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Bureau of Mines Information Circular/1986

Domestic Consumption Trends, 1972-82, and Forecasts to 1993 for 12 Major Metals

By Staff, Bureau of Mines, U.S. Department of the Interior, and Basic Industries Sector, U.S. Department of Commerce

UNITED STATES DEPARTMENT OF THE INTERIOR

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This report is based on a study conducted by the Bureau of Mines in cooperation with the —

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U.S. Department of Commerce

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

g	gram	st	short ton
lb	pound	tr oz	troy ounce
mt	metric ton	yr	year
%/yr	percent per year		

DOMESTIC CONSUMPTION TRENDS, 1972-82, AND FORECASTS TO 1993 FOR 12 MAJOR METALS

By Staff, Bureau of Mines, U.S. Department of the Interior,
and Basic Industries Sector, U.S. Department of Commerce

ABSTRACT

Consumption and intensity of use trends for 12 metals, by industrial end use, were estimated for 1972 through 1982 by the Bureau of Mines and U.S. Department of Commerce. The trends were then forecast through 1993 using standard statistical methods. The intensity of use measure selected is the quantity of metal consumed per constant dollar output of a specific industrial sector. The metals studied were aluminum, chromium, cobalt, copper, lead, manganese, nickel, the platinum-group metals, tin, titanium, tungsten, and zinc.

Average annual growth rates for the following 4 of the 12 metals increased from 1972 to 1982 as follows: aluminum, 1.00%; platinum-group metals (consisting of platinum, palladium, and iridium), 8.83%; titanium, 7.82%; and tungsten, 6.09%. Consumption for the remaining eight metals decreased at average annual rates ranging from 0.58% (copper) to 5.37% (manganese).

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Project coordinators for this publication were Patricia R. Devine, Divisions of Minerals Policy and Analysis (MPA), Bureau of Mines, and Robert C. Reiley, Basic Industries Sector (BIS), U.S. Department of Commerce. Staff assistance was provided by Barry Klein, Pamela A. Smith, Elizabeth Yaremchuk, Michael Zevitz, and Linda Johnson, all of MPA, and Donald Dalton of BIS. They were assisted by Bureau of Mines commodity specialists and BIS economic and statistical analysts (see chart), who analyzed the movements of both intensity of use and consumption for each metal. Also, Denny Place and Rod Renner of the Natural Resources Division, U.S. Federal Emergency Management Agency, provided historical data series for all metal consumption.

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Lead	William D. Woodbury	David Stonfer
Manganese	Thomas S. Jones	
Nickel	Peter G. Chamberlain	Graylin Presbury
Platinum-group metals	J. Roger Loebenstein	James Manion
Tin	James F. Carlin, Jr.	James S. Kennedy
Titanium	Langtry E. Lynd	James Manion
Tungsten	Philip T. Stafford	James S. Kennedy
Zinc		David Stonfer

SUMMARY

The objective of this study was to analyze changes in the domestic consumption of major nonferrous metals between 1972 and 1982, and to isolate the changes reflecting structural movements. Structural changes are permanent or long-term changes, as opposed to cyclical changes, which are primarily driven by the level of economic activity. The metals studied were aluminum, chromium, cobalt, copper, lead, manganese, nickel, the platinum-group metals, tin, titanium, tungsten, and zinc.

ANALYTICAL METHOD

The analytical method employed and the time period chosen for the study sought, to the extent possible, to separate secular or structural movements from those caused by variations in the business cycle. The method used is a variation of an approach called *intensity of use*, in which consumption per unit of gross national product (GNP) is regressed on time, with the refinement that the dependent variable (intensity of use) is a ratio of the quantity of metal consumed in a specific industry to the constant dollar output of that industry. In a simple trend analysis with annual data, as used in this study, the secular trend is the coefficient of time (the independent variable); non-time-related fluctuations are embodied in the error term of the equation. The use of the intensity of use ratio reduces fluctuations due to the economic cycle and growth. If both metal consumption and the user industry grow at the same rate, the intensity of use ratio is constant and exhibits a horizontal trend line over the period of study, indicating that metal use per unit of output is unvarying through the business cycle. If, instead, the numerator and denominator of the ratio are changing at different rates, indicating that more or less metal per unit of output is required, the trend line will not be horizontal but will have a positive or negative slope, as indicated by the regression coefficient.

In addition to using the intensity of use ratio, the particular time period selected for the study, 1972-82, further reduced the influence of cyclical variations and includes only one cyclical turning point (1975). This period was also selected because of data availability for most metals and their end uses. A longer estimation period would have introduced more points of inflection and perhaps shown the cyclical movements more clearly, but it also would have blurred the impacts of cyclical and structural variations which the intensity of use technique tried to separate. Although it is recognized that a number of causes can affect the movement of this ratio, the isolation of these causes by means of an econometric specification was not attempted in this study.

The analysis involved two major calculations. First, the regression equation estimates the best fitted intensity of use trend line over the 1972-82 period. The trend line is extended from 1982 to 1993, using the same equation. Second, the equation is algebraically transformed to estimate consumption (see appendix) and extended to 1993, using estimates of industrial outputs as independent variables. The discussion of each metal is accompanied by estimates of both the intensity of use and consumption by major industrial users. The two-stage calculation has the advantage of clarifying whether the metal's growth, or lack of growth, is largely a function of intensity of use or of economic performance.

The movements of both intensity of use and consumption for each metal were analyzed by economic and statistical analysts and by commodity specialists from the Bureau of Mines (BOM), U.S. Department of the Interior, and the Basic Industries Sector, U.S. Department of Commerce (DOC). This group subjectively determined the patterns of metal use in the industries and the validity of the forecasts based on the trends, the projections, and the Chase Econometrics forecast of industrial output. Projections of metal requirements for each industrial sector were adjusted, when necessary, based on the expert judgment of BOM and DOC staff.

RESULTS

A total of 232 regressions were run for the metals studied, varying in number from only 2 major end uses for titanium to more than 30 for copper, lead, and zinc. Usually there were fewer than five major users of each metal, whose combined use of the metal was over 60% of total consumption. These individual users are shown in the tables and figures for each metal; the remaining industrial uses are combined into the category "other uses". Only 19% of all the metals' intensity of use trends analyzed show increasing use of metal per unit of output.

Only the following four metals exhibited consumption growth during the 1972-82 period: aluminum, the platinum-group metals, titanium, and tungsten. Consumption of the remaining eight metals decreased at average annual rates varying from 1% (copper) to 5% (manganese, tin, and zinc) (table 1). Two of the four metals with growth in consumption derived their growth primarily from single markets: aluminum from metal cans, and platinum from catalytic converters. Only titanium and tungsten experienced increased consumption in a majority of end uses during the 1972-82 period. Over 90% of the total end uses for chromium, manganese, and tin required decreasing quantities of metal. (See table 1.)

It is possible for consumption to increase at the same time that intensity of use decreases if there is strong growth in the industry using the metal; i.e., less metal per unit but more units produced, and therefore, increased metal consumption. This is more clearly illustrated in individual cases than in the aggregate; e.g., in the use of lead in storage batteries. This effect, however, was not often observed during the 1972-82 period.

INDIVIDUAL METAL SUMMARIES

Aluminum intensity of use is level or decreasing in 18 of 21 industries in which it is used, but is increasing in its major market, metal cans, which accounted for 26% of aluminum consumption in 1982. Industry research is developing new and expanded uses of the metal and has contributed to good performance throughout the period. Consumption is projected to increase about 23% by 1993, and aluminum can use will constitute around 30% of total consumption.

Chromium intensity of use and consumption declined in every end use. Chromium remains a stable percentage component of specific alloy and stainless steels, but the mix of steels in marketed goods has changed to one that gener-

Table 1.—Summary statistics

Metal	Intensity of use (1972=1.0)[1] 1977	Intensity of use (1972=1.0)[1] 1982	Consumption (1972=1.0)[2] 1977	Consumption (1972=1.0)[2] 1982	1972-82 period: Av consumption growth rate, %/yr	1972-82 period: End use with decreasing intensities, %
Aluminum	0.833	0.685	1.073	0.976	1.00	62
Chromium	.758	.399	1.016	.569	−3.39	100
Cobalt	.789	.413	.941	.588	−2.74	75
Copper	.731	.574	.976	.817	−.58	78
Lead	.827	.560	1.065	.802	−1.17	87
Manganese	.864	.345	1.113	.492	−5.37	100
Nickel	.762	.461	.981	.657	−.43	80
Platinum group[3]	.802	.827	1.468	1.677	8.83	62
Tin	.671	.402	.864	.573	−4.77	91
Titanium	.964	.931	1.242	1.326	7.82	50
Tungsten	.987	.739	1.271	1.053	6.09	43
Zinc	.604	.387	.777	.551	−4.80	86

[1]In calculating an aggregate intensity of use, the consuming industry is the same for each metal: Final sales of durable goods in constant 1972 dollars, adjusted for inventory change. Each intensity is indexed to its 1972 ratio so that comparisons among metals may be made.

[2]Total actual consumption for each metal in individual weight units and indexed to 1972.

[3]Includes iridium, palladium, and platinum only.

ally includes steels requiring lower chromium content. The end-use products also contain less steel per unit value, or lower steel intensity as opposed to chromium intensity, but the combined or net effect of both these trends is to decrease chromium consumption. In addition, an increasing portion of the steel content of these products was imported steel, further reducing domestic demand for chromium. The negative trend is expected to continue.

Cobalt consumption had an average growth rate between 1972 and 1982 of –2.74%/yr. Because of major annual shifts in consumption, trends are difficult to determine. For example, cobalt consumption dropped 41% in 1975 but increased 41% in 1976. There is less variation in intensity of use, which shows declines in all uses except transportation (superalloys). This sector is the only end use projected to increase in either intensity of use or consumption. In 1983 superalloys consumed 36% of total cobalt used, and this use is expected to increase to 41% by 1993. The intensity of use and consumption levels will change dramatically if new cobalt-free superalloys are certified for jet engines.

Copper consumption declined during 1972-82, reinforced by the decline in its major market, the construction industry. Intensity of use increased in both heavy and general construction, which bodes well for periods of high growth, but declines in intensity of use in nearly every other end use will work against increased copper consumption in the future. Construction accounted for 53% of copper consumed in 1982 and is estimated to increase to 57% by 1993. Without new markets, copper consumption will continue to be dominated by cyclical forces. There is some indication that new markets are developing; in particular, consumers are increasingly interested in electric and electronic controls and gadgets and show a propensity to replace, rather than repair, such items as appliances and car radiators.

Lead use in gasoline will essentially cease in the forecast period, thereby making lead primarily dependent on its use in batteries. Intensity of use is declining for 27 to 31 end uses of lead, including all the major ones. Therefore, lead's projected consumption increase of 4.5% by 1993 is entirely a function of increased demand for batteries. Other uses are projected to decline gradually or, in the case of construction, to remain level.

Manganese demand, like chromium demand, is determined by the requirements of steelmaking. Unlike that of chromium, however, the manganese content in steel has declined as a function of production process changes. Therefore, demand for manganese has been impacted by two declining intensities of use: its own and that of steel. There is less manganese in steel, and less steel in its traditional products, such as automobiles. In addition, steel imports have increased, which further reduces manganese consumption by whatever amount would have been required to produce the steel domestically. In developing consumption projects, declines in consumption were assumed to be smaller (about 1.9% compounded annually) than projections based solely on the 1972-82 experience, because operation efficiencies in steel production were considered by the experts to be essentially complete in respect to manganese content.

Nickel consumption has declined at an average rate of less than 1%/yr annually from 1972 through 1982, a figure that showed substantial variation from year to year. Intensity of use declined in 16 of 20 markets tested including all the major end uses, primarily because of substitution of plastics in coatings, containers, automobile parts, and plumbing, and because of increased imports of stainless steel and the replacement of stainless steel. Estimated 1993 consumption is greater than that of 1982 by 17.6% (after being adjusted upward by the commodity analysts), but remains lower than the 1972 level. The increase in consumption is a function of growth in consuming industries outdistancing declines in intensity of use.

Platinum-group metals (PGM's) were analyzed separately as iridium, palladium, and platinum but reported together; PGM's show the strongest growth of the 12 metals studied, an average of 8.83%/yr. This is the result of automotive catalytic converter demand. New designs of the catalytic converter, however, require lower platinum content, and little growth in intensity of use is expected. Consumption of platinum and palladium is expected to grow fastest in this end use, because of growth in the automotive industry and of growing electrical and electronics industry consumption. Iridium consumption and all other platinum and palladium market intensities of use are decreasing, except for palladium in medical and dental equipment. Collectively the platinum-group metals should grow about 6%/yr in the 1983-93 period.

Tin consumption declined on the average 5%/yr between 1972 and 1982 and is expected to continue declining through 1993, but at a rate of 3.2%/yr. Intensity of use declined in 22 of 24 markets. Demand for the major end use, tinplate for metal cans, is diminishing owing to its replacement with aluminum, glass, and other materials and also to the thinner tin coatings on steel. The consumption of solder in automotive electronics, a small user of tin, is growing.

Titanium intensity of use in its largest market, the aerospace industry, was the same in 1982 as in 1972, but was greater than the 1982 level in every other year except 1976. Consumption also grew every year except 1976, owing to both intensity growth and growth in the aerospace industry. Nonaircraft industrial demand is showing exceedingly strong intensity growth, over 9% compounded annually, and in 1982 this end use constituted 30% of total titanium use. Both end uses are expected to show continued strong growth in consumption, and, more importantly, in intensity of use.

Tungsten has exhibited increasing intensity of use in three out of five end uses, including its largest market, metalworking machinery and tools. Growth is projected to nearly double the current rate by 1993 because tungsten is consumed primarily in high-growth industries, and because of increasing intensity of use in these industries. Continued high growth in machine tools and metalworking machinery will keep tungsten consumption increasing

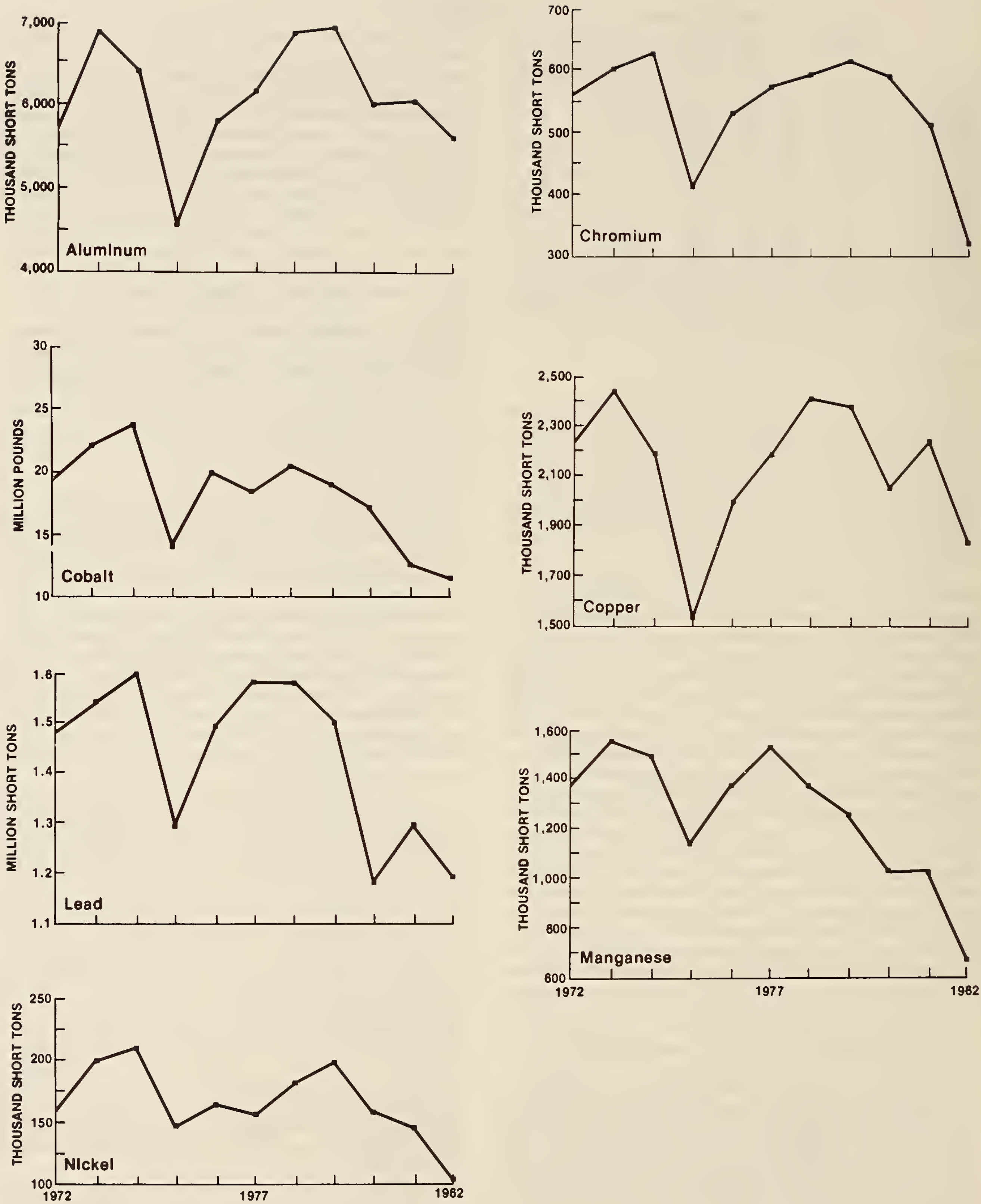

Figure 1.—Domestic consumption for 12 major metals, 1972-82.

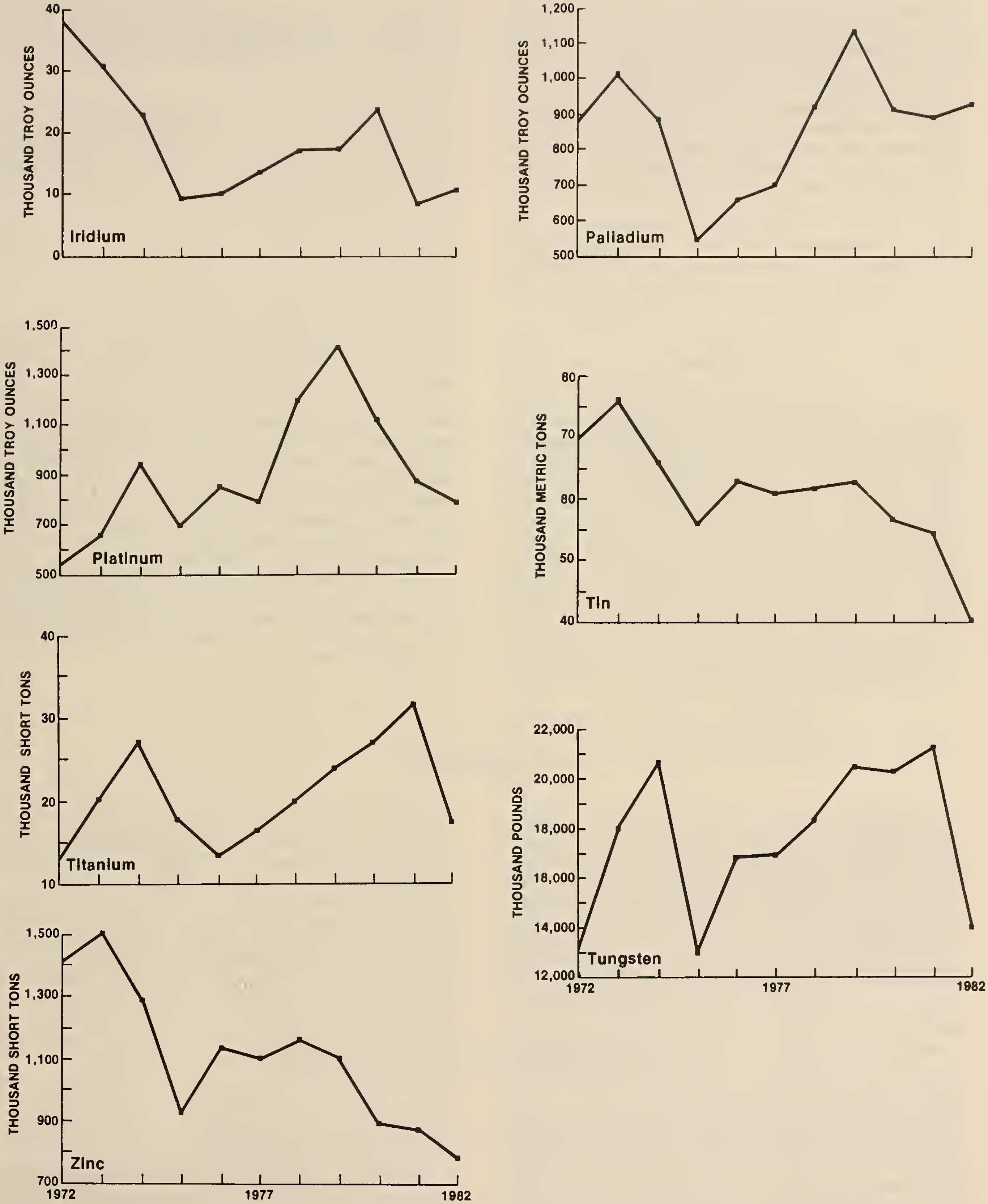

Figure 1.—Domestic consumption for 12 major metals, 1972-82.
Continued

even if intensity of use levels off. Consumption is expected to grow almost 6%/yr in the forecast years.

Zinc consumption as slab zinc decreased by nearly half between 1972 and 1982, with an average decline of 4.8%/yr. During this period zinc's intensity of use increased in only 3 out of 35 industrial sectors. Automobile downsizing, the frequent cause of metal consumption decline, was again the major cause of zinc's diminished demand. Construction use of zinc surpassed motor vehicles and equipment uses during this period, because construction intensity increased and zinc automotive intensity did not. Future growth in the automobile industry is projected to outpace construction growth (4.4% compared with 2.88% in the Chase model). Slab zinc consumption is expected to grow by less than 1%/yr in the forecast period of 1982-93, but 1984 data somewhat modify the pessimism of the forecast.

CONCLUSIONS

Significant changes took place in the domestic consumption patterns of the 12 metals in the study between 1972 and 1982. Total consumption and consumption per unit of output, or intensity of use, are decreasing for all metals except titanium, tungsten, and the platinum-group metals. Some of the metals in decline should recover to levels and growth rates exceeding their 1972 levels because important new uses have been established. Aluminum is an example of this category. In aggregate, however, the Nation's economy is substituting other goods for metals, buying more goods and services with lower or no metal content, and replacing some domestic goods containing metal with imports. If measured as consumption per capita or consumption per million dollars of real GNP, all metals in the study, except titanium, would be seen to decline. Total nonferrous metal consumption per capita in the United States declined 37.2% between 1972 and 1982. Total nonferrous metal consumption per million dollars real GNP declined 49.2% in the same period.

The analyses in this report have not quantified each cause of change, but have identified the major ones, by metal and by its end uses. One factor was singularly important in effecting changes in metal requirements: the energy price increases generated by the first major OPEC action of late 1973. The effects on the energy-intensive metal industries were strongest in 1975, as seen in the total consumption graphs (fig. 1). The 1975 reduction in total consumption stands out in each figure; averaged over all 12 metals, it is a 30.5% reduction. Four years of recovery followed, to be interrupted by the second major oil price increase in 1979. The consumption paths were already in a decline at the onset of the 1981-82 recession, further compounding the metal industries' problems. The average 1982 reduction of the metals studied was 27.2%.

Other causes common to the group have to do with trends rather than events, although these same events triggered some of the trends. The energy shocks are responsible for the shift to smaller cars and for many production process efficiencies requiring less metal input. Increasing competition in the world economy and the consumers' shift in expenditure patterns, however, are gradual long-term trends that were having perceptible effects on metal consumption before the energy crisis.

The study does not analyze policy options that might alter economic performance of the domestic metal industries. The policies that seem to have made profound differences in individual cases are the industry's initiatives in developing new markets.

INTRODUCTION

The Bureau of Mines initiated this study in order to measure changes in metal consumption and the effects of these changes on the domestic minerals industry. In 1983, the Bureau investigated metal consumption patterns, metal industry employment, trade, and comparable statistics in other industries in order to establish whether a problem in metal demand existed. Results of the study lend support to the hypothesis that basic structural changes could be taking place in the composition of U.S. industry, and that some changes did and would continue to affect the demand for metal. Service industries (including trade, finance, and transportation), which have been the largest component of gross national product (GNP)[1] since 1947, continued to grow faster than agriculture or manufacturing, widening the gap between services and all other spending, which indicated lower relative growth rates for construction and durable goods, the major markets for metals. Within the durable goods industries, major changes were also taking place. Technological developments resulted in the substitution of plastics and other materials for metals in manufacturing, and more efficient processing resulted in decreased metal use in some sectors.

The final products or industries that consumed metals changed as well from 1972 to 1982. Cars were downsized, structures were designed to use more glass and less metal, and food packaging moved beyond traditional metal or glass containers to include plastic and paper containers.

Metal demand has always been subject to cyclical changes, but the emerging metal consumption patterns suggested a departure from those of other sectors of the economy and from earlier periods in that there seemed to be an underlying downward trend for particular metal sectors. A longer period of observation (through more turning points) is needed before current theories regarding the impact of structural change can be accepted or rejected, but some facts are clear: First, that a problem may very well exist, and second, that analysis is required—at the very least, collecting information and measuring effects. Effective policies to deal with the observed declines in many of the U.S. metal sectors can only grow out of a sound information base and analysis.

In 1984, Bureau analysts joined in an effort with a group at the U.S. Department of Commerce (DOC). This report is a result of the joint venture. DOC had already published a report[2] in 1983 that examined the changes in use of six strategic metals. The analytical methods and data bases

[1]Council of Economic Advisors. Economic Report of the President. U.S. GPO, Feb. 1985, p. 245.

[2]U.S. Bureau of Industrial Economics (Dep. Commerce). Markets Trends and Forecasts for Selected Strategic Metals. BIE-SP83-2, Apr. 1983, 40 pp.

used by each group were similar, and both groups agreed to the study goals. The commodity specialists in the Bureau and their counterparts at DOC had in the past exchanged information in their research activities but had not heretofore collaborated on a project.

Although this analysis was performed by the Bureau, DOC participated in every phase, particularly in the interpretation of results. Each of the metal analyses is a joint product of the specialists of both groups. A third agency, the Federal Emergency Management Agency (FEMA), was also very helpful in laying groundwork for the project. The Natural Resources Division at FEMA provided historical data series for all metal consumption at the most detailed level: four-digit standard industrial classification (SIC)[3] sectors. In addition, FEMA offered its computer and software facilities for computation of the regression equations. The Bureau had intended to accept the generous offer, but availability of its own personal computers in time for the start of the project was more efficient.

ANALYTICAL APPROACH

An analytical method was selected to measure changes in metal industry growth compared with growth in other industries; this method is a variation of the intensity of use measure. Intensity of use is generally calculated as the ratio of the quantity of a given material consumed in a specific time period to a constant-dollar measure of GNP in the same time period. An effective variation used in this study compares each metal's consumption with the constant-dollar value of outputs of the individual industries that use the metal, since that ratio should show more stability than one using the more heterogeneous GNP. The tonnage of tin or copper or aluminum used in refrigerators, freezers, and household appliances is a function of both the recipe for making the appliance and the quantity produced. The production formula is one definition of the structure of the industry, and the intensity[4] calculation attempts to act as a surrogate for this measure.

The second determinant of metal consumption, the quantity of production in the industry using metal, can cause the metal demand to change in the opposite direction to the metal's intensity of use, if the industry's production is strong enough or weak enough. For example, in a high-growth construction period, strong demand for new structures may outweigh the demand for reduced metal in each structure (lower intensity), thereby causing total metal demand to increase in a declining intensity market.

The converse is also true; declining end-use markets requiring increased metal intensity can reverse the potential metal consumption surge that would otherwise occur. The intensity measure tends to reduce cyclical changes embodied in total consumption because they are per-unit measures. Intensities are always converted to consumption levels for the forecast years. The consumption forecast, or the quantity of metal required for any specific time period or scenario, is the product of intensity times a measure of industry's output of that time period or scenario. The resulting metal consumption estimate is the amount that will be consumed, if the production formula does not change, to produce exactly that level of industrial output.

The statistical technique used to estimate the best-fitted line around these intensity data points through the given time period (1972-82) is a simple linear regression, or a least squares equation. The equation describing the line has measurable statistical properties, which evaluate the accuracy of the fit and enable the analyst to determine if the intensity trend line is truly moving in a significant direction. Depending on the accuracy of the fit, and on the nature of changes anticipated in engineering and economic relationships, the analyst may project the trend line into the future and examine levels of intensity that might occur should the trend continue. In addition, metal consumption levels may be examined that would be required at the future intensity levels, given a forecast of future industry output. The forecasts of industry outputs used to derive metal consumption from intensity were estimated by Chase Econometrics Inc. at the four digit SIC level and are Chase's standard long-term interindustry forecasts, in constant 1977 million dollars, for 480 industrial sectors of the U.S. economy.

The intensities and their equations were calculated for the 1972-82 time period, or in some cases, through 1983, where data were available. The equations are shown in the appendix. For each metal, the trend was extended through 1993, and these intensities were the basis for estimation of projected metal consumption. Figures showing both intensity and consumption are shown for at least one major user of each metal. Tables of intensities and consumption of all major users are given. The entry marked "other" in the consumption tables is the sum of all remaining uses for that time period.

INTERPRETATION OF RESULTS

There are several points regarding the intensity method which analysts must consider when interpreting results of the consumption forecast and projections of intensities. First, the statistical calculations make no assumption regarding cause and effect. The factors determining events that cause the numerator or denominator to move up or down must be identified by the analysts. In this study, for example, in examining the intensities plotted against time, a low point occurred in 1975 for each metal. The cause can be associated with the OPEC oil embargo and energy price increase.

Other movements are less easily associated with possible causes. Irrespective of the cause(s), an intensity equation with a high R-square statistic (a measure of the preci-

[3]The Standard Industrial Classification (SIC) defines an industry based on its primary economic activity, thereby aggregating similar products or functions under one heading. The code was developed by Office of Management and Budget to promote the comparability of statistics. The four-digit codes each denote a specific industry.

[4]For convenience, "intensity" is used for "intensity of use" throughout this report, except as necessary for clarity.

sion), whether of positive or negative slope, is an indication that structural changes are present. An intensity that remains stable through economic cycles, represented in the denominator by industry output cycles, is interpreted as a metal largely unaffected by structural change. Finally, an intensity that varies imprecisely, or a function with a low R-square and no logical movement around known events, says little about the presence or absence of structural change, and no conclusions are drawn.

The method assumes definitions are constant, but in the case of industry output they usually are not. Even at disaggregate levels, the total industry mix of products changes frequently. The machinery sector, for example, is defined for a given mixture of machines and given levels of each. An intensity calculation could change by shifting production levels from one type of machine to another in its mixture without altering metal composition in components of any one type, but the shift would change the calculated intensity.

The position of imports in the calculations is also relevant. Imports are included in the metal consumption data, because both domestic and imported metal are consumed by the end-use domestic industry and are inseparable in any product containing the metal. Imports treatment becomes a problem when imports occur further along in the production process, since there is a high probability that many imported products contain metal. Consider the calculation of copper used in automobile parts and accessories. Copper purchased by the automobile parts and accessories industry is the basis of the intensity value; copper purchased as a component of an imported intermediate part, perhaps in a car radio or radiator, is not identified as copper, and therefore not included in the copper estimate. Given the 48.6% increase in imports of durable goods during the time period covered by the study, it is almost certainly true that actual metal intensities are underestimated. This effect could be measured using input-output analysis, which is not a part of the present study, but an already completed study does give rough estimates of this difference.[5]

For primary nonferrous metal manufacturing, the metal contained in imported intermediate production goods added 21% to the imports in 1978. It had increased to 21.5%, by 1979 and to 25.2% in 1980; but in 1981, it dropped to 22.8%. In 1982, contained nonferrous metals in imported goods added 24.7% to direct imports of nonferrous metals.

For this study metal consumption is estimated specifically for primary (some data included scrap) metal used in the United States for the manufacture of intermediate and final goods, and that quantity is a direct function of domestic manufacturing demand. It is only indirectly a function of imports containing metal, in that those imports replace and reduce domestic production of similar goods. Given the level of domestic production, the metal intensity and consumption calculated here are for the primary metal used in that production in all of its phases. One might conclude that in the absence of the semimanufactures imports, domestic manufactures might have required increased consumption of about 25% in primary nonferrous metal, but the additional metal might also have been imported.

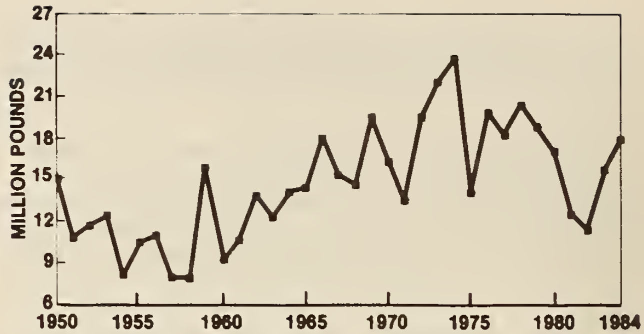

Figure 2.—Cobalt apparent consumption, 1950-84.

A final consideration in interpreting results is the time period covered in the estimation. If a metal's consumption is cyclical, the position within that cycle, i.e., the time span when estimates are developed, will determine the trend direction. Figure 2, which charts cobalt consumption for the period 1950-84, shows three such periods: declining use until the late 1950's, high growth through the 1960's, and declining growth in the 1970's. For an estimation of a single straight line representing the 1956-80 period, the growth periods would strengthen the upward trend and project increased future growth. Isolating the 1972-82 period, however, would project negative growth in the future. Only the informed analyst can know of events taking place within the industry and the economy that might reverse the trend. Without that knowledge one is left to assume present trends will continue, if other events do not interrupt the process. In this study the starting assumption was that the calculated trend is the expected metal demand for the given industry, but the demand was adjusted by the specialists based on their analysis of events that would significantly impact metal consumption.

ALUMINUM

The consumption of aluminum was examined in this study for 21 end-use sectors in the U.S. economy. Consumption increased in six sectors from 1972 to 1982, dominated by metal can use, which accounted for 10% of total aluminum in 1972 and rose to 26% in 1982 (table 2). Intensity of use of aluminum is given for six major sectors in table 2. Aluminum intensity of use remained relatively stationary, with just 3 of the 21 sectors having increased intensity of use during the period.

Total U.S. aluminum consumption[6] was essentially the same in 1972 as in 1982, with significant variations in intervening years and in individual industrial sectors. (See figure 1.) Aluminum industry research, which has developed new and expanded uses for the metal, has contributed to aluminum's good performance compared with that for other metals throughout this historical period. For 1982 to 1993, total domestic aluminum consumption is projected to increase more than 23%, although the intensity of use ratios are forecast to decline for 10 of the 21 end uses studied.

[5]The U.S. International Trade Commission (ITC) used this technique to study trade-related employment; to the extent labor quantities are proportional to the quantity of the goods labor produces (i.e., labor to output ratios are constant), their results can at least give an order-of-magnitude estimate. The time period covered by the ITC study is 1978-82, a period of high growth in imports. Source: U.S. International Trade Commission (DOC). U.S. Trade Related Employment. Publ. 1445, Oct. 1983, 126 pp.

[6]Total to domestic users of end-use shipments of aluminum products in the United States (including scrap). Consumption data are unavailable for aluminum, so shipment data are used instead. Distribution to end uses is based upon Aluminum Association, Census Bureau, BOM end-use data, and DOC estimates. Source: Aluminum Association: U.S. Bureau of Census (DOC); U.S. International Trade Administration (DOC); BOM end-use data.

Table 2.—Aluminum intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND SHORT TONS PER MILLION 1977 DOLLARS				
Metal cans	0.078	0.200	0.267	0.345
Sheet metal work	.104	.071	.064	.047
Electric and electronic equipment	.007	.005	.003	.001
Motor vehicle bodies, parts, and accessories	.006	.007	.008	.009
Transportation equipment	.006	.004	.004	.003
CONSUMPTION, THOUSAND SHORT TONS				
Metal cans	569.5	1,477.0	*1,729.1	*2,089
Sheet metal work	535.6	364.0	465.9	429
Electric and electronic equipment	530.3	455.0	404.0	207
Motor vehicle bodies, parts and accessories	520.8	512.0	786.0	1,017
Transportation equipment	253.4	209.0	210.0	162
Other	3,337.4	2,593.0	3,209.0	3,013
Total	5,747.0	5,610.0	6,804.0	6,917

[1]These industries (except "other") accounted for 54% of total aluminum consumption in 1982.
*Subjective value selected over regression value.

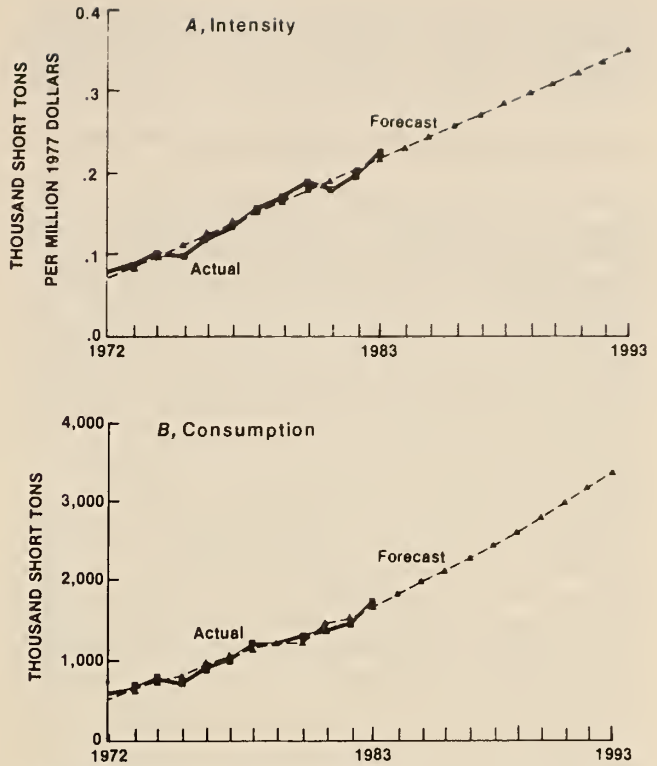

Figure 3.—Aluminum intensity of use and consumption in metal cans, 1972-93.

Metal Cans (SIC 3411)

The largest end-use market for aluminum is metal cans. Aluminum has replaced steel as the primary raw material for making beverage cans. As a result, the intensity of aluminum consumption (tonnage) in metal can output (measured in 1977 dollars) increased substantially during the 1970's and early 1980's. The aluminum share of the metal can market is expected to continue to increase but at a slower rate than indicated by the 1987 and 1993 calculated projections, despite the very high correlation,[7] as illustrated in figure 3. The primary reason is that the beverage can market is now virtually dominated by aluminum; therefore little additional substitution of aluminum for steel in this end use is possible.

Aluminum has room for expansion in the food market, where it has a 4% share, but the market, which is dominated by tinplated steel, is only half as large as the beverage can market. Also, the adoption of aluminum by food container manufacturers is expected to be a relatively slow process because of uncertainties regarding the aluminum-steel price relationships coupled with capital costs associated with such a conversion. The conversion costs are more significant for food cans than they were for beverage cans because of the technology needed to prevent collapse of aluminum cans by (1) introducing internal pressure (which is already provided by carbonation in beverage cans) and (2) building structurally strong aluminum cans. For these reasons, the projected trends shown in figure 3 were rejected by commodity experts, and the lower consumption level shown in table 2 was substituted.

There will be slight growth in the metal cans market, hence in aluminum consumption, resulting from increased population, but this will be partially offset by production of thinner wall cans in the future. This will enable production of 10% more cans per pound of aluminum.

Aluminum industry efforts have been largely responsible for the success of aluminum cans. Through its efforts, more than 50% of all aluminum cans are recycled, which has helped aluminum to be competitive with relatively cheap steel cans. The aluminum industry is also conducting research on producing an aluminum foil food pouch that can be used in microwave ovens.

Sheet Metal Work (SIC 3444)

Sheet metal work constituted 6.4% of 1982 aluminum consumption. It is an end-use market comprising a number of products consumed by the construction industry; for aluminum, it consists primarily of residential siding. The intensity of use in the sheet metal industry has declined substantially (32%), primarily because of substitution of vinyl siding for aluminum siding. This was largely the result of the changing aluminum-vinyl siding price relationships. During the 1970's aluminum siding's narrowing price advantage over vinyl siding disappeared completely, such that in the late 1970's vinyl siding prices gained an ever-growing advantage over prices for aluminum siding. The result was that, in 1982, shipments of vinyl siding for the first time exceeded those of aluminum siding; recently, vinyl siding has had a 60% share of the market compared with 40% for aluminum. Vinyl siding, in addition to a lower price, has the advantage that the color is distributed throughout the material and its appearance is less easily marred by scratches and dents. Aluminum, on the other hand, dents easily and has only a surface coat of paint, making scratches more noticeable.

The quantity of aluminum to be used in construction applications relative to competing materials is expected to continue declining as use of vinyl continues to increase and as wood, the traditional material, regains some of its former market share. Given these considerations, the aluminum intensity and consumption for 1987 and 1993 reasonably represent this end-use. Other sheet metal and construction

[7]An R-square of 0.98 for this equation is shown in table A-1.

uses will remain the same or increase, since the construction industry will in itself increase, but its aluminium siding component will cause total aluminum use in this market to decline.

Electric and Electronic Equipment (SIC 3600)

The ratio of aluminum consumption to total output value of electric and electronic equipment has declined and is expected to continue to decline. One reason is the miniaturization of electronic equipment, which has substantially reduced the amount of aluminum consumed per unit produced (intensity); another is substitution, primarily by plastics. Also, aluminum use for household wiring, which began in the 1960's, declined sharply in the 1970's, when such uses were associated with fires. Aluminum wiring requires special compatible electrical outlet boxes and contacts, and problems arise when aluminum wiring is installed with outlet boxes and brass screws designed for copper wiring. For example, because aluminum has a different expansion coefficient than brass screws, a change in temperature can cause an electrical contact to become loose, generate heat, and possibly result in a fire. In spite of the fact that correctly installed aluminum wiring does not pose a fire hazard, building codes do not allow aluminum wiring in some areas, and some builders and homeowners try to avoid aluminum wire where it is permitted.

Despite technological developments, such as copper-clad aluminum wire, to try to reduce the chance of fire from incorrectly installed wiring, the outlook is pessimistic for aluminum household wiring since it cannot easily overcome its negative image as a potential fire hazard. Aluminum use in household wiring and in steel-reinforced cable is not expected to increase.

Motor Vehicle Bodies, Parts, and Accessories (SIC 3711, 3714)

The intensity of aluminum in the motor vehicles and motor vehicle parts and accessories industry (see table 2) has increased 1.6%/yr from 1972 to 1982 and is forecast to continue to increase at a slightly higher rate to 1993, about 2.4% compounded annually. Motor vehicles and motor vehicle parts and accessories have been a growing market for aluminum because of the need to reduce vehicle weight and thereby improve gasoline mileage. This market for aluminum offers substantial growth potential, one of the most important being the substitution of aluminum for copper in automobile radiators. Aluminum radiators, however, have two disadvantages: they are more difficult to produce and more difficult to repair than copper radiators. However, ever for copper radiators, the trend has been that fewer radiators are repaired each year; they are instead exchanged for new radiators. Therefore, this difficulty to repair aluminum radiators may not be a serious disadvantage. Early problems encountered in producing aluminum radiators have been overcome through technology.

Transportation Equipment (SIC 3700)

Aluminum consumption in transportation equipment (which includes all industries classified under SIC 37 except motor vehicle bodies, truck and bus bodies, motor vehicle parts and accessories, and truck trailers) declined during the 1970's. This decline is primarily the result of substitution of other materials for aluminum, such as composites in the aerospace industry.

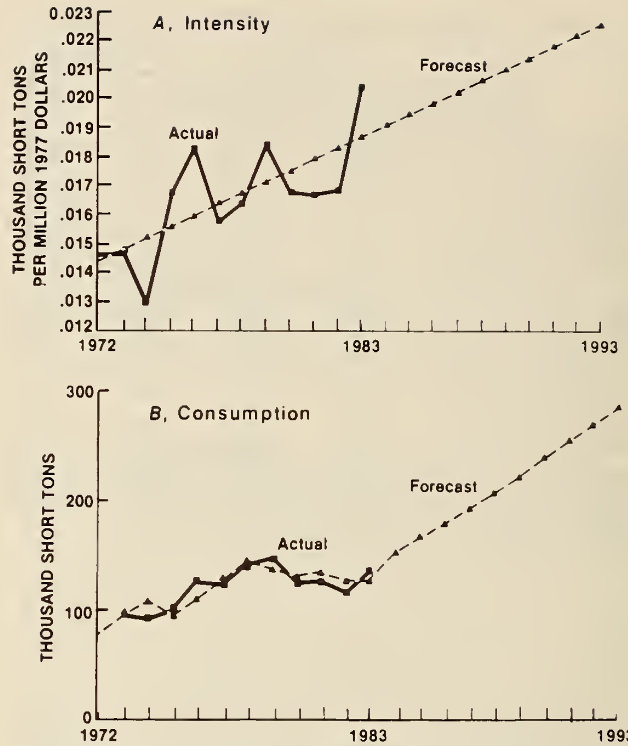

Figure 4.—Aluminum intensity of use and consumption in internal combustion engines, 1972-93.

Aluminum consumed in this end-use is forecast to remain virtually unchanged from 1982 to 1987, and then decline from 1987 to 1993 (table 2). However, the introduction of such new aluminum products as aluminum-lithium alloys should cause the decline to be halted and aluminum use to remain stable through the early 1990's.

Other

This category contains about 100 end uses not covered by the five major end uses discussed above. One of the more important uses within this category is internal combustion engines, n.e.c. (SIC 3519), which includes diesel, semidiesel, or other internal combustion engines, n.e.c., for stationary, marine, traction, and other uses. As figure 4 illustrates, aluminum for this use did not follow the general pattern of metals consumption. For most metals, both the ratio of consumption to industry output and the consumption volume show a decline in 1975 and then another downturn in 1979 that extends into the 1980's. However, for aluminum in internal combustion engines, the intensity and volume both declined in 1974, but then rose sharply in 1975 and 1976, and then increased sharply again in 1983.

The reason for aluminum's strong performance in this end-use is that aluminum is substituted for steel and cast iron in various engines and engine parts. Aluminum is lighter in weight than steel and cast iron, an important consideration in marine engines and especially in outboard motors.

Comparing the two graphs of figure 4, one sees that despite the widely fluctuating actual consumption ratio, the estimated tonnage tracks closely with the actual tonnage. Therefore, although the R-square was low at 0.51, one can still put confidence in the estimated consumption ratio and tonnage for the forecast period.

Table 3.—Chromium intensity of use and consumption

Industry[1]	Actual		Forecast	
	1972	1982	1987	1993
INTENSITY OF USE, THOUSAND SHORT TONS PER MILLION 1977 DOLLARS				
Chemicals industry	0.00095	0.00065	0.00058	0.00045
Refractory industry	.13	.025	0	0
Fabricated metal products	.00053	.00027	.00028	.00015
Machinery	.00033	.00010	.00005	0
Transportation	.00048	.00025	.00028	.00018
Other metal	.132	.066	.064	.034
CONSUMPTION, THOUSAND SHORT TONS				
Chemicals industry	94	81	90	87
Refractory industry	87	27	*20	*20
Fabricated metal products	41	21	28	19
Machinery	55	23	16	*16
Transportation	64	30	45	33
Other metal	220	137	162	101
Total	561	319	361	276

[1]These industries (except "other metal") accounted for 57% total chromium consumption in 1982.
*Subjective value selected over regression value.

CHROMIUM

Consumption[8] of chromium is determined largely by the requirements of its largest user, steelmaking, which consumes at least half of all chromium (table 3). Chromium enhances hardenability, creep resistance, impact strength, and resistance to corrosion, wear, and galling. Stainless steels contain between 12% and 36% chromium; alloy steels, cast irons, and nonferrous alloys contain less chromium, the amounts varying with the individual product and grade. Given a specific alloy or stainless steel grade, the average quality of chromium required varies little. Once the total production value is known, chromium tonnage can be calculated with less error than for other ingredients. This should lead to calculated intensities with small variation over time, regardless of consumption level, but several considerations do introduce error in the measure.

First, the end-use values reflect varying amounts of steel included in their industries' uses; i.e., the stable chromium intensity is superseded by the unstable steel intensity. Secondly, the imports of steel do not alter steel intensity calculations, but do alter chromium intensity calculations, because imported steel's chromium content was consumed where that steel was made and its presence is lost in this calculation of domestic consumption.

Third, the heterogeneity of the product (i.e., the constant-dollar value of machinery or fabricated metal products), can be unchanging and yet its content may vary considerably with the mix of products and even with a single product, if it is made differently. For example, alloys are becoming cleaner and more efficient in response to such special-purpose uses as catalytic converters and mufflers. The amount of chromium might remain constant, but the product price increases, even in constant dollars, since such advances represent a product change in the marketplace rather than an inflationary change. Therefore, in such cases the intensity of use decreases but does not actually represent a change in chromium use per unit of physical output.

Chemical Industry (SIC 2800)

The steep and lengthy decline of apparent consumption in the chemical industry is reflected by the 2.8%/yr decline in intensity of use. Consumption figures stay steady due to chemical industry growth. The predicted 1987 and 1993 consumption levels are consistent with the steady nature of historically reported consumption values.

Refractory Industry (SIC 3297)

Refractory industry chromium consumption and intensity series show extreme and steady decline, resulting from technological changes in steel-producing furnaces, the historical end-use for chromium-containg refractories. A new lower level will eventually smooth out this curve, but demand is not yet steady. The regression consumption value goes to zero, given the strength of the decline; however, that has been replaced by an extension through the forecast period of the actual 1983 value.

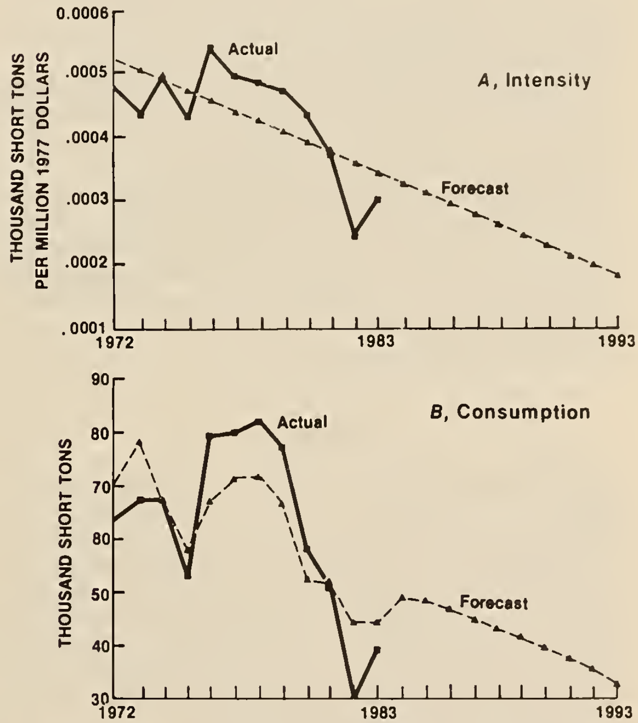

Figure 5.—Chromium intensity of use and consumption in the transportation industry, 1972-93.

Steel (SIC 3400, 3500, 3700, 9999)

The remaining categories, defined by the American Iron and Steel Institute, are stainless and heat-resisting steel shipments by market class data adjusted by apparent consumption. These categories are fabricated metal products, machinery, transportation, and other metal.The large fluctuations of the steel industry are responsible for the decline in chromium consumption by a factor of two during the analysis period and are responsible for 4 yr of continuous declining consumption. The analysis period includes a significant recession (1982-83) and two large energy price increases. The importance of the recession on steel sectors was tested by recalculating all intensities and concomitant consumptions by statistical analysis run through 1981.

The degree of decline is significantly reduced by eliminating data points for these last 2 yr (1982 and 1983). These are the lowest values of intensity during the analysis

[8]Total U.S. industrial demand, including secondary (scrap) supply. All data are adjusted from reported to apparent consumption levels, as obtained from the Bureau's commodity specialist for chromium. Source: Papp, J. F. Chromium Ch. in Minerals Facts and Problems, 1985 Edition. Bu Mines B 675, 1985, table 8 (p. 147).

period and result from the steel industry's recession from 1978 to 1983. The predicted chromium consumption in the three steel categories depends on how stainless steel production recovers over the projected time period.

Fabricated metal products demand for chromium per unit and in total halved during the 1972-82 period. The precipitous drop from 1979 pulled the intensity forecast down, but strong growth in the fabricated metal products industry (4.1% annual growth) throughout the forecast period keeps the consumption level from falling much below its current level.

The machinery sector forecast by Chase Econometrics grows even faster—nearly 6%/yr—but the use of chromium through the historical period declined so intensely that its use reaches zero in the 1990 projection. The equation is quite good, with an R-square of 0.83, but logic transcends statistics and the 1987 value was selected as a floor value. This level, 16,000 st, could be reduced by continued increases in both steel and machinery imports, but it is assumed here to be a lower limit.

The transportation sector use also continues to decline in intensity, but volume of consumption stays at current levels, owing to the slower intensity change and the transportation sector growth. (See fig 5.)

None of the forecasts is at the level considered likely by commodity specialists in terms of actual chromium content of those industries' outputs, because, as has been stated, the level is fairly stable. The Bureau projects growth[9] through 1987 close to the levels shown (see table 3) but assumes a new upward growth thereafter that the intensity of use trend does not project.

COBALT

Cobalt imparts high-temperature strength and corrosion resistance to superalloys. It is one of the most strongly magnetic elements known and has the highest Curie point, the temperature above which a material loses its ferromagnetic properties. It is the best known binder for making cemented carbides. Cobalt is considered a strategic metal; i.e., essential to national defense, primarily because of its use in superalloys for jet engines. Superalloys are also the largest end use of cobalt since 1978, and the only end use with increasing ratios of intensity.

Although cobalt's apparent consumption[10] in 1982 of 11.5 million lb was at its lowest level since 1961, it rebounded in 1983, reaching 15.7 million lb. Between 1972 and 1982 cobalt consumption decreased 41.2%, or 3.5% compounded annually, but individual changes from one year to another were so varied throughout this 1972–83 estimation period that extreme movements in demand made it difficult to discern trends in consumption and intensity with statistical significance. For example, in 1976 consumption increased 41% after decreasing by the same large amount in 1975.

The cobalt projections were not used as calculated from the regression equations, because they trended too severely and the statistical properties of the regressions were poor, except for cobalt use in magnets. In seeking to find a level all analysts agreed was likely, the commodity specialists acknowledged there were many unknowns, especially in transportation and electrical end uses. They therefore agreed to disagree, and the consumption total presented in table 4 is the lower of the two. The alternative forecast, proposed by the BOM commodity specialist, projects total consumption of 17.5 million lb in 1987 and 22.5 million lb in 1993. These alternative consumption projections are based on cobalt's strong rebound in 1984, new electrical uses, delayed certification of cobalt-free superalloys, and continued strong economic growth. The following discussion of each end use describes in what way the consumption forecasts differ from the regression values.

Table 4.—Cobalt intensity of use and consumption

Industry	Actual		Forecast	
	1972	1982	1987	1993
INTENSITY OF USE, THOUSAND POUNDS PER MILLION 1977 DOLLARS				
Chemicals, paints, and ceramics and other	0.121	0.063	0.042	0.003
Machinery and machine tools	.044	.026	.018	.003
Electrical	.325	.059	*.059	*.059
Transportation	.093	.096	**.129	**.129
CONSUMPTION, THOUSAND POUNDS				
Chemicals, paints, and ceramics and other	6,195	3,683	3,136	*6,000
Machinery and machine tools	2,907	1,886	*2,259	*2,259
Electrical	6,069	1,867	*2,350	*3,022
Transportation	4,294	4,015	*7,014	*7,916
Total	19,456	11,451	14,759	19,197

*1982 intensity substituted for calculated value.
**1983 intensity substituted for calculated value.

*Subjective value selected over regression value.

Chemicals, Paints, Ceramics and Other[11]

Catalysts and driers are the major consumers in this broad end-use category. Cobalt is used in catalysts to facilitate the removal of sulfur and vanadium from crude oil. In paints it is used as a drier to accelerate and control the rate of drying. Other uses, such as ceramics and radioisotopes, are important but of low volume, usually just several hundred thousand pounds annually.

Cobalt used in chemicals, paints, and ceramics increased until 1974, and then both consumption and intensity fell in 1975. Thereafter, cobalt intensity and tonnage changed direction each year until 1979 when both declined and have been slow to recover. Both consumption and intensity were up in 1983, but neither had reached the pre-1979 level.

Consumption in these end uses is not expected to fall below the projected 1987 estimate of 3,136,000 lb. Since most "sweet" oil has been discovered and consumed, it is increasingly likely that now prevalent "sour" oil will require catalysts for sulfur removal.For this reason the 1993 consumption level was raised from the very low calculated level of 247,000 lb to 6 million lb.

Machinery and Machine Tools

One of the major end uses of cobalt in machinery and machine tools is cemented carbides, in which consumption has been little reduced by substitution, because no effective general substitute exists at this time. There are, however, cobalt-free substitutes in some applications but with a loss of productivity. Figure 6*A* shows, however, that intensity of use has steadily declined. The upward movement in 1978 and 1979 cycled back down for the next 3 yr.

[9]Work cited in footnote 8.

[10]Total apparent consumption of U.S. industrial demand (includes primary demand and secondary supply). Apparent consumption = primary production + production from old scrap + (imports − exports) + (beginning inventories − ending inventories). Source: Kirk, W. S. Cobalt Ch. in Minerals Facts and Problems, 1985 Edition. Bu Mines B 675, 1985, pp. 171–183.

[11]SIC codes not listed for end uses because data source did not use SIC distribution.

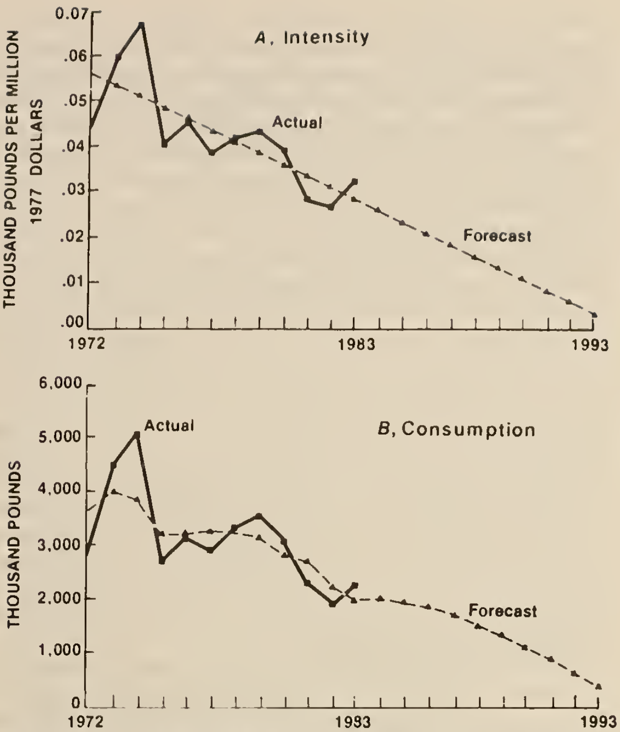

Figure 6.—Cobalt intensity of use and consumption in machinery and machine tools, 1972-93.

If the projections followed the decreasing intensity path, 1987 consumption would be only 1,694,000 lb and 1993 consumption would be just 367,000 lb. (See fig. 6*B*.) Unless a more satisfactory substitute for cobalt in cemented carbides for cutting tools is found, such a projection is unlikely. If the 1983 intensity of 0.032 continued, projections for 1987 would increase to 2,966,000 lb and for 1993 to 3,655,000 lb. This seems unlikely, considering the steady intensity decline since 1972. Therefore, the forecast was adjusted to a floor level not less than the actual 1983 amount of 2,259,000 lb.

Electrical

Consumption of cobalt in electrical uses (magnetic alloys) is the end-use area experiencing the greatest change in recent years. Substitution for cobalt in magnets began in earnest during the perceived cobalt shortage of 1977-78 and continued afterwards.

Most of this substitution was in the form of ceramic magnets replacing cobalt-containing magnets, particularly when alnico magnets used in speakers were replaced by lower cost ceramic magnets. Substitution is still occurring and will continue because of the introduction of the newly developed iron-neodymium-boron magnets. These new magnets are more powerful, and should become less expensive, than those containing cobalt.

The use of non-cobalt-containing magnets has been so pervasive in this sector that intensity of use was reduced 82% in just 10 yr. The statistical trend has a high R-square, and consumption is brought to zero before 1987 with these intensity of use ratios. Given that most of the changeover could have already taken place, and the possibility of market development for two new applications, the intensity for 1982 was assumed to continue through 1993, attaining a consumption level of 2.4 million lb in 1987 and nearly 3.0 million lb in 1993.

The first new application is the use of an 85% Co–15% Ni alloy coating on video recording tape. The alloy significantly increases the storage capacity of the tape, allowing videotape cassettes and, therefore, video cameras to be much smaller, lighter, and more portable. Sales of the new, smaller videocassettes and cameras began in 1984. The second new application is the use of 80% Co–20% Cr alloy coating on computer diskettes, resulting in a 10-fold increase in storage capacity. Before these new diskettes reach the marketplace, however, computers must be redesigned so that their mechanical components are more precise and their electronic components are more sensitive.

Transportation

In 1983 transportation, or superalloys uses, accounted for 5.6 million lb, or 36% of total cobalt consumption. The primary use of superalloys is in jet aircraft engines. Cobalt intensity of use in superalloys has varied between 0.065 and 0.129 (100%), but shows a definite pattern of increase from 1972 to 1983. Certifying a new superalloy for use in aircraft is a costly and time-consuming process; therefore, new superalloys are developed only if performance benefits can be achieved. A joint program by the U.S. Air Force and Pratt & Whitney has developed two new cobalt-free superalloys. These superalloys were developed for the next generation of jet fighter aircraft and are reported to offer significant improvements over currently used materials. General Electric, which won authorization to become an engine producer for the F-16 fighter in 1984, has developed technologies that lower cobalt content 30%[12]. If these new superalloys prove to be cost efficient, their widespread use would profoundly affect the use of cobalt in superalloys. With new superalloy certification, the level could be considerably lower than that shown in table 4.

The superalloys demand for cobalt is assumed to continue increasing, but the rate is not expected to remain at the high level calculated in the trend. The calculated cobalt consumption for transportation in 1993 at 0.156 intensity of use is 9.6 million lb, an annual growth rate of 6.5%, or twice as fast as the transportation industry's projected growth by Chase Econometrics. Given possible future substitutions, an intensity of use of 0.129, the 1983 estimate, is therefore substituted for the forecast period, and this results in estimates for the 1987 and 1993 transportation demands for cobalt, of approximately 7 million and 8 million lb, respectively.

COPPER

Copper[13] and its alloys, bronze and brass, have been important materials in the development of civilization for thousands of years. Copper has grown from early use in tools and weapons to today's extensive use in electrical products. It is present in every structure and every vehicle and used in nearly every industry in the economy. Copper, steel, and aluminum are the most ubiquitous metals in worldwide manufacturing. The United States remains the largest con-

[12]Fortune. Cutting Dependence on Strategic Metals. V. 112, No. 2, July 22, 1985, p. 69.

[13]Consumption of domestic reported refined copper was based on data from the U.S. Bureau of the Census, the Copper Development Association, the Census of Current Industry, and estimates that included only scrap used to produce refined copper. Source: U.S. Bureau of Mines. Minerals Yearbook, various years Chapter on Copper.

Table 5.—Copper intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND SHORT TONS PER MILLION 1977 DOLLARS				
Heavy construction	0.006	0.007	0.009	0.010
General construction	.005	.007	.008	.009
Air conditioning and heating equipment	.013	.010	.009	.008
Household appliances	.010	.009	.008	.007
Motor vehicle parts and accessories	.005	.005	.005	.005
CONSUMPTION, THOUSAND SHORT TONS				
Heavy construction	590	512	*627	*696
General construction	555	456	*581	*643
Air conditioning and heating equipment	111	80	102	102
Household appliances	90	77	96	107
Motor vehicle parts and accessories	178	138	*175	*191
All other industries	714	566	630	599
Total	2,238	1,829	2,211	2,338

[1]These industries accounted for 69% of total copper consumption in 1982.
*Subjective value selected over regression value.

sumer of copper and until recently was copper's largest producer. Domestic uses are primarily associated with electrical applications (table 5).

Copper intensity of use and consumption were calculated and projected for 32 industries, 5 of which are listed in table 5. These five represent 68.1% of total consumption in 1972 and 69% in 1982. Of the remaining 27 end uses of copper, shown in the table as "Other," 5 exhibit modestly increasing intensity of use.

During the 1970's the intensity of copper use experienced a broad-based and significant decline. Estimates of this decline vary depending on methodology. DOC, in a 1983 study[14], reported that the ratio of copper consumption to constant dollar shipments declined in 58 of 77 copper end-using industries from 1972-80. The reasons for copper's decline are varied but have generally been attributed to automotive and products downsizing, design changes to conserve materials or increase efficiency, and substitution primarily by aluminum.

Although the decline in intensity is not expected to continue at the same rate as in the 1970's, and could in fact be offset by gains in some areas, the future for copper demand is at best mixed. During the next several years it is likely that copper use will decline in two major markets: Aluminum will increasingly replace copper in automotive radiators, and fiber optics will erode copper's telecommunications markets. The growth in copper tonnage consumed, therefore, will become increasingly dependent on the growth and the production of its end-use products; i.e., less copper per unit but more units produced. Such a situation would make copper increasingly vulnerable to economic downturns and recessions, which would cause a sharp drop in major end-use production.

Construction (SIC 1500, 1600, 1700)

Although copper intensity of use grew in the construction industry during the historical period, its consumption declined. The reason for this was that construction output was greatly reduced during the recession. Copper intensity of use in the construction industry has moved primarily with the economy at large, but with some interesting exceptions. In 1974 both the construction output and copper used in construction (intensity) started an enormous downward slide as a function of the OPEC action, and both hit bottom in 1975. Afterwards copper recovered faster than the construction industry, as indicated by the increasing intensity of use. Copper continued its upward trend until the effects of the second OPEC action brought it back down in 1979, while the construction industry fluctuated throughout the period. Copper intensity of use in heavy construction declined 19% and in general construction 22% in 1975, but within 2 yr each had reached a peak higher than before the energy price increases. Again, in 1981, a recovery started, but the recession stifled it; and in 1983, even though consumption was again increasing, intensity was still declining. The overall effect, however, is an increasing trend due to the remarkable strength of the 1976-78 rebound.

Since the trend is too dramatic to be realistic for longer periods, the intensities shown in table 5 were not used to calculate the projections. Instead, the actual intensities for 1983 are assumed to continue throughout the forecast period, and construction use of copper is estimated to grow with the expected growth of construction, which Chase Econometrics forecast at 2.88%/yr. The following paragraphs discuss the individual uses and expected growth of copper in construction.

For convenience, copper usage in the three broad types of construction activity covered under SIC groups 1500, 1600, and 1700 is aggregated into two industrial uses, with SIC 1500 allocated to SIC 1600 and SIC 1700. The first group, SIC 1600, called heavy construction, relates to refined copper consumed in making wire, sheet, and tube for use in heavy construction such as electrical and communication transmission lines, railroads, street maintenance, marine construction, and other construction except buildings. The second group, SIC 1700, called general construction, includes all copper used in work done by special trade contractors and includes copper used in plumbing, heating, air conditioning, roofing, and electrical work done at the site. Copper and copper alloys are used extensively in all of these groups for electric power production and transport, communications wire and connectors, water carrying and spinkler systems, central air conditioning equipment, heating systems, roofing, and many special uses such as in desalinization plants. More than 50% of the annual refined copper is in response to the growing needs of the construction industries.

Since most of the markets served by the wire industry fluctuate with the business cycle and are highly sensitive to interest rate changes affecting the construction industry, virtually every wire and cable end-use market experienced a decline from 1979 through 1982 associated with the rise of interest rates during that period. Since 1982, however, both residential and nonresidential building activity started expanding. This is assumed to continue through the forecast period. New residential construction is a major source of building wire demand, accounting for nearly 20% of insulated wire demand.

The demand for high-voltage power wire and cable corresponds to the Nation's demand for electric energy, and to a large extent to the growth of the utility sector providing that energy. After the two large oil price increases and as many recessions, growth in electric energy generation contracted from its 7.5% annual growth rate in the 1960's to a 2.2% rate in 1982. The long-term outlook, however, is for growth in electric energy generation to pick up through the remainder of the 1980's, although at a slower pace than in the last decade.

[14]U.S. Department of Commerce. Market Trends and Forecasts for Selected Strategic Metals. BIE-SP83-2, Apr. 1983, p. 14.

The communication wire market is expected to remain competitive and, among electrical uses, provide one of the best opportunities for growth because of the large customer base it serves. Cable television subscriptions have grown 13.1%/yr since 1970, and the industry now purchases about $250 million worth of flexible and semiflexible coaxial cable annually. Some of the more optimistic forecasts have estimated that this wire market will triple over the next 5 yr as large metropolitan areas bring their systems into service. Copper will compete with aluminum and ultimately fiber optics in this use and in other electrical and communication uses.

Copper and copper alloy materials produced in the United States for use in the construction industry in 1983 experienced significant increases over 1982 production, reflecting the rebound of the economy and the successful penetration by copper into market segments enjoyed by competing materials. While aluminum has made considerable impact on the high-voltage power wire market, copper has reestablished its competitive position in the building wire and transformer wire markets. Although the price of optical fiber has fallen in recent years, its price means that it currently can be cost efficient only when used in high-signal-density areas such as long-distance and interoffice trunking applications. Use in subscriber loop area remains to a large degree uneconomic at this time.

Although continued import penetration is expected, a revival in some important markets such as large-diameter tubing and roofing is expected to continue. Fire sprinkler systems for hotels, hospitals, apartments, and nursing homes have been increasing; copper systems are easier to install and are of better quality than alternatives, and are therefore preferred in this use. A new Ni-Cr-Cu alloy with good erosion-corrosion resistance at high-flow velocities is competing with stainless steel and titanium tubing in electric powerplants. The use of large-diameter copper tube for water supply systems in commercial building is also an application for copper plumbing that is expected to grow. Copper is recognized as a potential solution for preventing corrosion and scaling and is gaining ground in this area because of these qualities.

Other volume uses expected to expand are the roofing market, comprised of shingles for houses, motels, and industrial buildings, and sheet roofing for high-rise and other commercial buildings. This market increased in the United States by about 20% in 1983. Some advantages of copper roofing are ease of installation, durability, little or no maintenance, and resistance to wide temperature variations and heavy snow covers. Changes in architecture towards steep roofs are also a factor promoting the increased use of copper for roofing.

Total demand for copper and copper alloy materials used in construction in the United States is forecast to grow at a rate parallel to the growth in the U.S. construction industry, but with two possible departures. First, the copper consumed by U.S. semifabricators and destined for this economic sector will deviate from the expected use as a result of continued increases in imported semimanufactured and manufactured items. The Copper Development Association reports copper metal shipments (including imports) to the building construction market increased by 13.8% from 1983 to 1984, and total construction increased by 18.1%. The second possible departure is the assumed steady intensity, which results in an understatement of copper consumption and could be in error. It could continue to grow, both in the traditional uses and in some new ones, given the popularity of different electronic gadgets, additional telephones, solar panels, and sprinkler systems—all of which bring higher copper intensity of use in construction. To the extent these uses expand and are not replaced by imports, the construction forecast is underestimated.

Air Conditioning and Heating Equipment (SIC 3585)

The use of copper in this market has been declining for the past decade, partly as a result of the oil crises of the early and late 1970's. (See table 5 and figure 7.) The decline in copper intensity appears to be the most pronounced during the late 1970's, as higher energy costs caused consumers to demand more energy efficient products. Improved consumer energy awareness and insulation allowed for the installation of smaller units. In addition, the general downsizing and miniaturization of products, along with some substitution, caused copper use to decline. The intensity of copper use in this demand sector is expected to continue to decline slightly during the next several years; this decline, however, will be far less pronounced than that which occurred during the 1975-80 period.

The tonnage of copper use by this market also declined (table 5), on average, during the last decade. The tonnage decline, however, was more a function of the overall economy and construction activity than of a decline in copper intensity. The recessions of 1975, 1980, and 1982 had a serious negative effect on building activity and copper consumption. During the next decade the air conditioning and heating market is expected to undergo study expansion. This expansion will cause the tonnage of copper consumed in this market to regain some ground lost during the 1970's.

Household Appliances (SIC 3630)

Copper intensity of use in many appliances has been reduced during the past 10 yr as a result of downsizing,

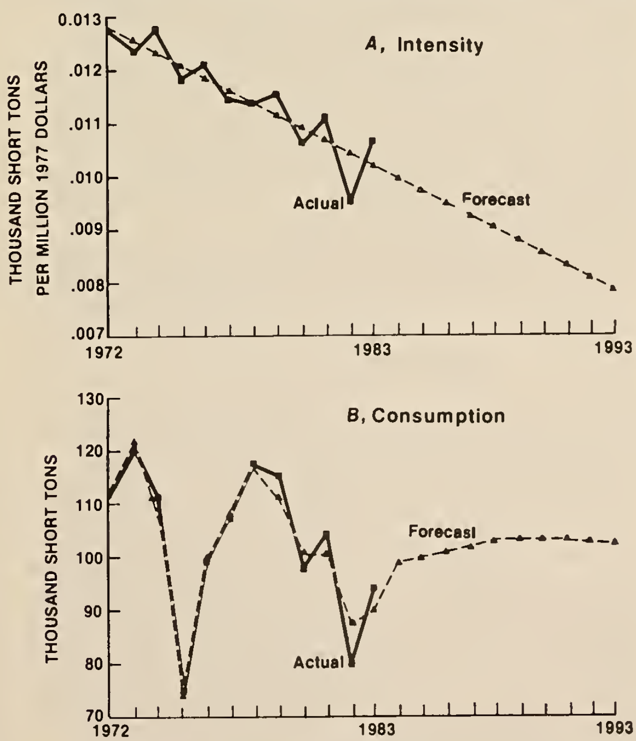

Figure 7.—Copper intensity of use and consumption in air conditioning and heating equipment, 1972-93.

design changes, and substitution. This overall reduction has been tempered by an increase in electronic components and controls during the last few years. In any case, the use of copper per unit has declined since 1970, and this decline is expected to continue during the next several years but at a reduced rate. The expected reduction should result primarily from continued downsizing and substitution but again will be tempered by an increase in electronic controls.

Although intensity has declined, the tonnage of copper used in appliance applications has shown uneven growth during the past 10 yr, due in general to the growth in appliance demand during nonrecessionary years. New appliances, and the miniaturization and new design of many traditional appliances, coupled with an increasing use of electronic controls and a trend to replace rather than repair, seem to have stimulated appliance demand and increased the number of appliances per household. The demand for household appliances should undergo a strong expansion during the next decade, causing copper tonnage used in this market sector to rise.

Motor Vehicle Parts and Accessories (SIC 3710)

The automotive industry is a major user of copper, mainly in radiators, wiring harnesses, electrical and electronic equipment, and accessories. Copper consumption by the industry underwent significant changes during the 1970's, in terms of both intensity of use and product mix. The intensity estimate is constant, but the regression is poor and reflects a great deal of variation over the time span.

The oil crisis of the early 1970's had a profound effect on the intensity of copper use, as automotive manufacturers redesigned and downsized their fleets. Government-mandated mileage requirements directly contributed to vehicle weight reductions. Copper use per vehicle dropped during the early downsizing stages; most of this decline was due to the smaller radiators required for four- and six-cylinder engines. Smaller cars also use shorter cables and wires, and therefore, less copper. The downward trend in copper use abated in the early 1980's as an increase in automotive electrical and electronic applications offset declines. During this period consumers increasingly demanded vehicles with options such as stereo systems, electric seats, windows, and defoggers.

Despite an anticipated increase in automotive electronics, the intensity of copper use per vehicle is expected to decline slightly during the next several years. The substitution of aluminum for copper in radiators will result in this decline. In 1985 Ford replaced copper radiators with aluminum in at least eight models; General Motors uses aluminum in its *Fiero*, *Corvette*, and *Firebird* models. It is likely that by the 1987 model year, 50% of the automotive radiator market will consist of aluminum radiators.

The future for copper consumption by the automotive sector appears somewhat brighter when considered in terms of tonnage. Domestic motor vehicle production appears to have bottomed during the 1982-83 recession and has since experienced a healthy recovery. Domestic motor vehicle production should experience study growth through the early 1990's. This growth will be enhanced by increased domestic production of foreign-designed automobiles. The overall increase in vehicle production should cause copper consumption to regain most of the tonnage losses experienced during the 1970-80 period.

Table 6.—Lead intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND SHORT TONS PER MILLION 1977 DOLLARS				
Batteries	0.51	0.44	0.42	0.38
Gasoline additives	.008	.003	0	0
Construction: Total	.0008	.0006	.0005	.0005
General	.0003	.0002	.0002	.0002
Heavy	.0005	.0004	.0003	.0003
Ammunition	.13	.09	.07	.04
Pigments	.0028	.0018	.0013	.0007
CONSUMPTION, THOUSAND SHORT TONS				
Batteries	726.6	776.4	959.0	1,034.0
Gasoline additives	279.1	131.4	0	0
Construction, total	78.0	40.5	47.0	40.0
Ammunition	84.7	48.8	62.0	38.0
Pigments	89.2	67.1	71.0	47.0
Other	227.7	121.2	90.9	80.1
Total	1,485.3	1,185.4	1,229.9	1,239.1

[1]These industries accounted for 90% of total lead consumption in 1982.

LEAD

From 1972 to 1982 total U.S. lead consumption[15] declined at a compound annual rate of 1.9%, from 1.5 million to 1.2 million st (table 6). Similarly, there has been a decline in lead intensity of use for all but 3 of the 31 lead end-use sectors tested. Lead's intensity of use has declined because of advances in technology, Government regulations in the form of environmental and workplace standards, and substitution of less hazardous or more economic materials.

For the 1983-93 period, total annual domestic lead consumption is projected to remain at about 1.2 million st. The battery industry, by far the largest lead consumer (65% of consumption), is forecast to grow significantly. However, this growth will be offset by declines in other consuming industries, especially the production of tetraethyl lead discussed under gasoline additives, the second largest use in 1972 to 1983 (18% of consumption). Other important consuming sectors are pigments, ammunition, construction,and the electrical and metalworking industries.

An important factor holding down primary lead consumption is increasing lead recycling. It is anticipated that 55% of total U.S. demand could be met from metal recovered from old scrap compared with 45% now. Such recovery will be made possible by less dissipative uses; i.e., uses in which lead is dispersed throughout the environment and thus essentially "lost." For example, there will be virtually no tetraethyl lead production, a use where lead cannot be recovered. By contrast, almost all lead from batteries can be recovered.

Batteries (SIC 3691)

The battery industry, the largest end use of lead, increased to over 70% of lead consumption in 1983, about 890,000 st. The major end-use markets for lead-acid batteries are (1) automotive starting-lighting-ignition (SLI) systems; (2) uninterrupted power supply (UPS) systems for hospitals, computers, and banks; (3) conventional standby emergency telecommunications and lighting systems; and (4) electromotive traction batteries for electric vehicles (EV's). Technological improvements in battery design and the downsizing of automobile batteries have resulted in a

[15]Total U.S. consumption of primary and secondary lead, including scrap. Distribution to end uses based upon BOM end-use lead data and industry judgments. BOM reports lead in metric rather than short tons. Sources: U.S. Bureau of Mines. Minerals Yearbook, various years. Chapter on Lead. U.S. International Trade Administration (DOC).

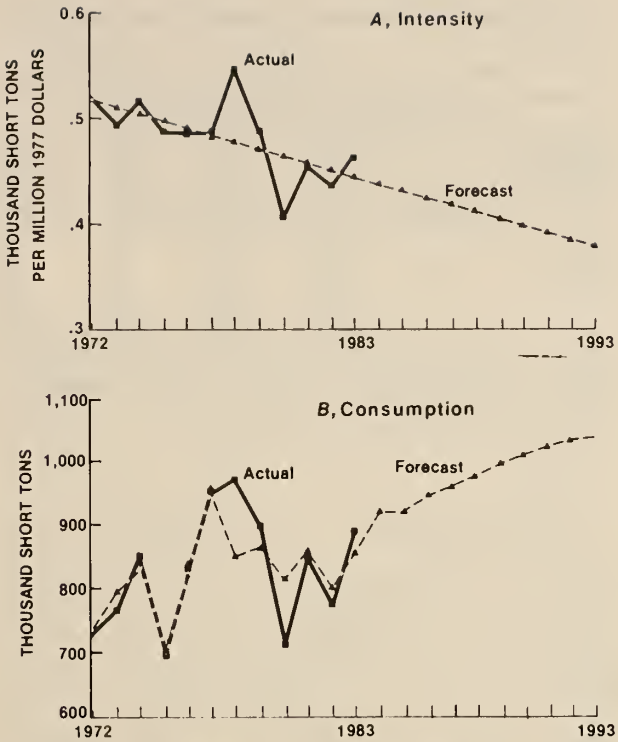

Figure 8.—Lead intensity of use and consumption in storage batteries, 1972-93.

steady decline in lead intensity of use of 14% from 1972 to 1982. This decline in intensity of use is projected to continue through 1993. (See table 6 and figure 8*A*.)

However, output in the battery industry is projected to increase rapidly in the forecast period, producing a significant increase in lead consumption in this important market by 1993. (See table 6 and figure 8*B*.) The forecast of 1 million st of lead consumed by the battery industry in 1993 could be conservative, if the industrial-traction sector attains a growth rate of 10%/yr. This growth rate is a possibility, considering that substitution for lead-acid batteries in conventional end-uses appears unlikely during this century and that additional demands for very large load-leveling batteries by both utility networks and customers, such as public mass transit systems, is likely. The market for automotive batteries is expected to grow 3%/yr in this period. Under these circumstances, total U.S. lead consumption could reach 1.4 million st in 1993 if electric passenger cars are commercially developed.

Gasoline Additives (SIC 2869)

The intensity of use of lead in the tetraethyl lead (TEL) industry, part of SIC 2869, has declined more than 50% since 1972. Laws regulating the amount of lead permitted per gallon of leaded gasoline have caused this decline.

In March 1985, the Environmental Protection Agency (EPA) issued its final ruling on the lead content of gasoline. This ruling reduces the amount of lead permitted per gallon of gasoline to 0.1 g as of January 1, 1986. This standard represents a 90% reduction from the previous standard of 1.1 g, substantially reducing the amount of lead consumed in TEL in the future. A total ban on lead in gas is also likely for 1988. A ban on leaded gasoline is not a new idea, nor would it be limited to the United States. Many European countries have expressed a desire to reduce or eliminate lead in gas by the end of this decade. Since up to 50% of U.S. TEL production is exported, future world demand for the product is uncertain and continued decline in TEL intensity of use is expected. TEL consumption could reach zero in this country by 1990.

General and Heavy Construction (SIC 1520, 1540)

Consumption of lead in the construction sector represented the fifth largest end use of lead in the United States in 1982. The intensity of use for lead in this sector also has declined 25% from 1972 to 1982. This long-term decline in lead use was due to substitution of less expensive, lighter, and less hazardous materials. The use of lead in roofing, flashing, piping, and caulking has declined in general and heavy construction as the use of plastics, aluminum, and steel has grown.

The rapid decline of lead use in the estimation period has slowed somewhat in the early 1980's. The compounded annual rate of 6.8% decline has now dropped to a much lower rate, about 2.7%/yr. In fact, lead use in the construction industry could rise in the future if the lead industry can overcome the general public's concern about lead in the environment. Significant market potential exists in new uses, such as for a stabilizing agent in asphalt roofing shingles and plastic pipe and other shapes. In addition, traditional uses of lead, such as in lead sheet for use in sound barriers and radiation protection, and lead and plastic laminates for cablesheathing, could see a resurgence in demand in the future.

Ammunition (SIC 3482)

Lead used in small arms ammunition represents the fourth largest end-use sector in 1982. As with most other sectors, the intensity of use for lead in this sector has declined (5.7% compounded annually) over the past 10 yr. Lead in this sector is used for sporting ammunition in the form of shot and small-caliber bullets; there is little use of the metal in military ordnance today. Lead shot used in radiation shielding applications, such as double-annulus pipe at nuclear reactors, is also included in this sector.

Lead intensity of use is projected to continue its long-term downtrend. Lead consumption for this sector is projected to rise modestly and then fall through the early 1990's. A reversal of this trend will be contingent upon the growth of radiation shielding applications, which could prove substantial with revived nuclear reactor construction and renewed interest in firearms.

Pigments (SIC 2816)

This generalized end-use category includes all paints, pigments, glass and ceramic products, and chemicals such as "chrome yellow" (lead chromate) derived from lead oxides. It does not include battery oxides or chemicals from metallic lead, such as gasoline additives or lead diamyldithiocarbamate, an antioxidant for asphalt. The specific uses within this general category have changed more drastically over the last two decades than those within any of the other categories due to the growing demand for "TV glass" (picture tubes and cover plates) and the elimination of lead-based indoor paints. For instance, in 1983 the use of lead oxide for TV glass represented about 40% of this category, and red lead oxide for undercoat or anticorrosion protective paints about 25%. The projection of consumption

in 1993 is 47,000 st. However, if a major highway and bridge rebuilding scenario occurs, and the shipbuilding industry is revitalized, demand could easily reach 84,000 st in that year, assuming continuing growth of conventional TV technology. The projection for 1993 of 47,000 st total demand could occur if lead anticorrosive uses were substantially replaced and light-emitting diode or liquid crystal technology were substantially utilized in the TV industry. Lead intensity of use is expected to continue to decline in the 1983-93 period.

MANGANESE

As in other industrialized countries, a high proportion of domestic manganese demand[16] is determined by requirements in steelmaking. The trend in steel's consumption of manganese is toward lower use owing to more efficient operations, such as determining the manganese content by computer. A lower manganese requirement also occurs when sulfur has been removed first. Manganese intensity in steel sectors dropped by about half between 1972 and 1982, and total consumption dropped 50.8% (table 7). The process of decreasing manganese use in steel is not quite complete but will not continue much longer. The strong intensity of use regression trends in the analysis are assumed to continue only until 1987 in the steel end uses, after which the trend is interrupted and constant intensities are assumed to hold.

The manganese content varies in steels according to grade, but in most instances does not exceed 2%. The steel production mix variations in steel chemistries can be disregarded in estimating manganese use in steel-related end-use categories. Thus, to a first approximation, the allocation of manganese demand can be made solely on the basis of steel demand as developed by the Bureau from compilation of shipments tonnages by the American Iron and Steel Institute.

The three most important steel-manganese end-use sectors by percentages in 1982 are construction at 42.2%; transportation at 32.4%; and machinery at 25.4%.

The most significant development affecting these steel-manganese demand sectors during 1972-82 was a decline in relative importance of the transportation sector, which in 1972 was the highest use, at 37%. Automobile downsizing was an important cause of an appreciable decrease in consumption by the transportation sector. Not only was there a reduction in the sheer bulk of cars, but steel was used more efficiently in certain applications by use of higher strength steels. The trend to a lower absolute quantity of steel-manganese demand for the transportation sector resulted in displacement of transportation by construction as the leading manganese end-use sector. Demand by the construction sector was comparatively stable as a nearly constant fraction of total steel demand exclusive of transportation. The relative importance of demand by the machinery sector diminished slightly, by only 1%, toward the end of the 1972-82 interval because of increased imports of machinery and weak markets, particularly for agricultural machinery.

The sector labeled "Other" in the tables comprises six other uses: cans and containers, appliances and equipment,

Table 7.—Manganese intensity of use and consumption

Industry[1]	Actual[2] 1972	Actual[2] 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND SHORT TONS PER MILLION 1977 DOLLARS				
Transportation	0.0031	0.0015	0.0010	*0.0007
Construction	.0024	.0015	.0012	.0005
Machinery	.0023	.0008	*.0004	*.0004
CONSUMPTION, THOUSAND SHORT TONS				
Transportation	359	149	140	*108
Construction	356	194	196	*152
Machinery	255	117	*90	*117
Other	399	213	*204	*172
Total	1,369	673	630	549

[1]These industries accounted for 68% of total manganese consumption in 1982.
[2]Actual numbers may differ from source because of redistribution and independent rounding of numbers.
*Subjective value selected over regression value.

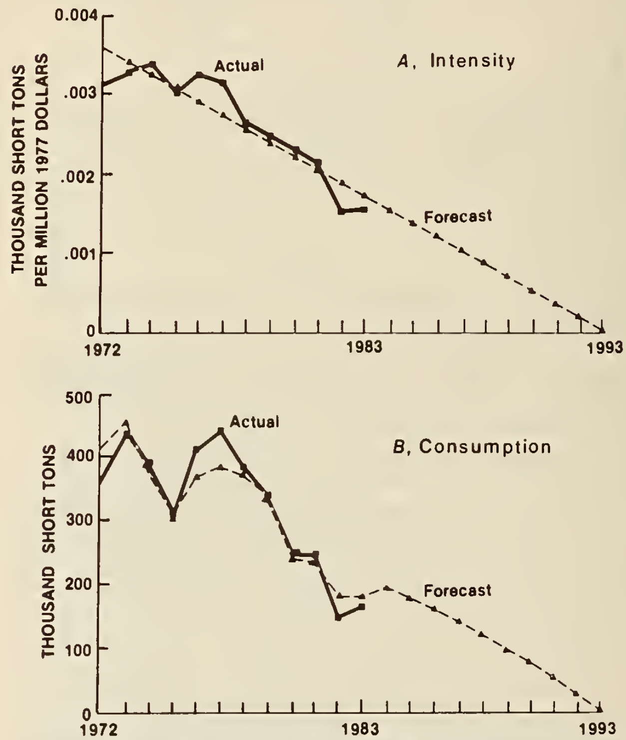

Figure 9.—Manganese intensity of use and consumption in the transportation industry, 1972-93.

oil and gas industries, chemicals, batteries, and as a residual. The statistical significance of manganese trends, except for oil and gas industries and batteries, was unusually high, exhibiting strong downward trends with low error terms. Even so, the forecasts were not uniformly accepted by the specialists. In some cases, the decline was caused by an event that had run its course, such as the efficiency change in steelmaking. Future intensities were therefore adjusted to a more realistic level. In other cases, the downward slope was considered to take into account future events not built into the equation, and the consumption decline was allowed to stand. Such a case is chemicals, in which manganese use as an oxidant by Tennessee Eastman will be discontinued in 1986.

Figure 9*A* shows the extreme negative slope of manganese intensity of use in transportation, and figure 9*B* the expected downward path of manganese consumption derived from that intensity. Both reflect the dilemma of

[16]Total U.S. primary demand. For this study 80% of the "Other" category is distributed proportionately to construction, transportation, machinery, cans and containers, appliances, and oil and gas industries. Source: Jones, T. S. Manganese. Ch. in Mineral Facts and Problems, 1985 Edition. BuMines B 675, 1985, pp. 483-498.

separating mathematical and other professional judgments. The regression equation has excellent statistical properties, an R-square value of 0.85; however, it does not account for future events—for example, when the process of decreasing manganese in steel will be completed—or for other outside events that will interrupt the smooth downward projections. In the judgment of mineral experts, future events will modify the decline during the forecast period, as the slight upturn in 1983 indicates. This is the theory behind changes made to the 1993 projections of all tabled values.

Transportation (SIC 3700)

Intensity of use in the transportation industry decreased by half from 1972 to 1982 and is forecast to continue to decrease to 1993. However, the Bureau's commodity specialist advises that further substitution is limited, since production efficiency is nearly completed. The 1989 intensity of use of 0.0007 was taken as a limit and was substituted for the calculated value of 0.00002. The replacement intensity changes the manganese consumption in 1993 from 3,000 st to 108,000 st. (See figure 9*B*.) A most significant development affecting the steel-manganese demand sectors during the period was a decline in growth of the transportation sector. The industry output in constant dollars moved erratically during the 1972-82 estimation period, decreasing and increasing equally often. Between 1982 and 1993 the transportation sector is projected to grow 4.1%/yr, bringing up steel-manganese growth commensurately.

Construction (SIC 1500, 1600, 3440)

The declining consumption and intensity of use of manganese in the construction sector are projected to continue to 1993. The ratio in 1982 is 0.0015, declining to 0.0012 in 1987 and to 0.0005 in 1993. Use of new construction materials, replacing steel and higher strength steels of increasing efficiency, is assumed to continue; however, the trend should bottom out earlier than the projection indicates, leaving the regression estimate correct for 1987 but low for 1993. The value in table 7 was calculated at nearly 100,000 st for construction but has been changed to the 1990 level of approximately 150,000 st, as it is not expected to fall beneath that low level.

Machinery (SIC 3500, 3610, 3620)

The ratio of manganese consumption to output value of the machinery industry decreased about 5% each year from 1972 (0.0023) to 1982 (0.0008) and is forecast to continue its downward slope. This long-term decline in intensity is attributed to more efficient production processes in steelmaking, which is expected to change less in the forecast period than calculated. The intensities of 0.0003 in 1987 and 0 in 1993 were therefore adjusted to a constant ratio of 0.0004 (fig. 10*A*), which is the 1986 ratio. As a result, machinery consumption of manganese will not reach zero, as forecast in 1993. (See figure 10*B*.) Instead, machinery consumption is estimated at 90,000 st for 1987 based on the adjusted intensity and at 117,000 st for 1993.

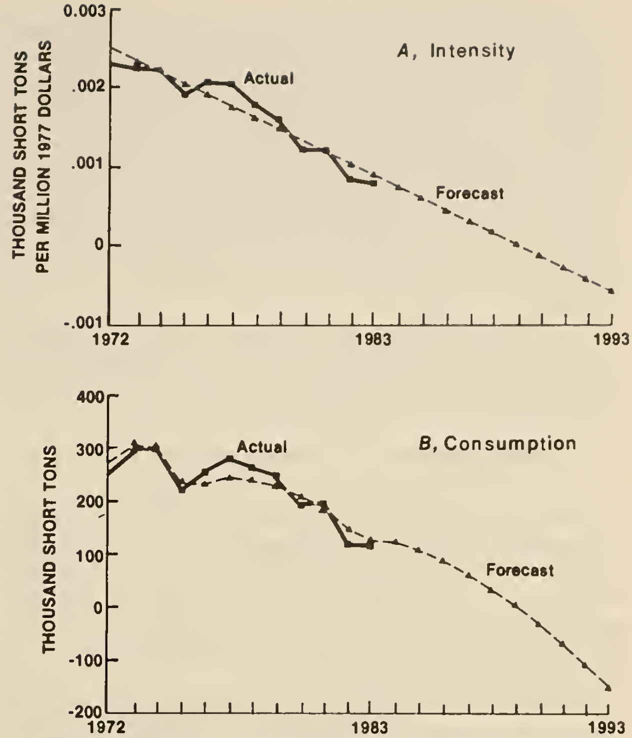

Figure 10.—Manganese intensity of use and consumption in machinery, 1972-93.

Table 8.—Nickel intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, SHORT TONS PER MILLION 1977 DOLLARS				
Fabricated metal products	0.81	0.53	0.46	0.29
Construction	.290	.087	*.087	*.087
Chemical and allied products	.050	.031	.021	*.021
Machinery except electrical	.260	.130	.091	.011
Electric and electronic equipment	.234	.098	.022	*.022
Transportation	.177	.142	.174	.171
CONSUMPTION, SHORT TONS				
Fabricated metal products	66,309	42,427	49,012	36,608
Construction	5,483	3,232	*3,731	*4,291
Chemical and allied products	4,878	3,794	3,238	*3,810
Machinery except electrical	25,112	16,046	16,806	*16,806
Electric and electronic equipment	16,539	9,596	*9,596	*9,596
Transportation	23,773	17,316	*28,513	*31,759
Other	16,206	11,570	18,819	19,439
Total	158,300	103,981	129,813	122,309

[1]These industries accounted for 89% of total nickel consumption in 1982.
*Subjective value selected over regression value.

NICKEL

Nickel is used primarily as a steel-alloying additive to improve strength and resistance to wear and corrosion. The domestic steel industry uses nearly half (45%) of the U.S. primary nickel requirements. About 80% of this amount is used to produce stainless and heat-resisting steel, the balance to produce alloy steel. Domestic stainless steel production is approximately 70% nickel-bearing. Historically, about 40% of domestic primary nickel consumption is in consumer durables (cars, refrigerators, and other household appliances), and the remainder is in capital goods (commercial and industrial buildings, and industrial machinery and equipment).

Nickel consumption[17] and intensity of use were calculated and projected for 21 end uses, of which 6 are shown in table 8. These six end uses (fabricated plate work, contract construction, chemical and allied products, machinery, electrical and electronic equipment, and transportation) consumed 90% of the 1972 consumption total and 89% of the 1982 consumption total. Substitution and imports were major contributors to a 41% decline in domestic nickel requirements for the construction industry between 1972 and 1982. Intensity of use declined even further (70%) indicating structural changes in its use as opposed to recession declines.

From 1972 to 1982, the average rate of consumption decrease was 0.43%, while intensity of use decreased for 16 of the 20 end uses. Substitution and imports were major contributors to this decline in nickel requirements.

Fabricated Metal Products (SIC 3400)

Fabricated metal products includes end-use items such as shipping containers, cutlery, plumbing fixtures and fittings, plating, boilers and duct work, and other fabricated metal used in commercial and institutional kitchens, hospitals, dairies, and chemical processing plants. Within the fabricated metal products group, plating has been a significant nickel end-use area.

Nickel-plated plumbing fixtures and fittings and automobile bumpers and side trim were once large nickel end-use areas. During the 1970's, however, less costly and lighter weight substitutes such as plastic and aluminum displaced much of the domestic nickel demand requirements of these end-use areas. Initially, the switch to less costly plastic plumbing fixtures and fittings and rising automobile imports began to reduce domestic nickel demand for these plating applications. However, the reduction became more dramatic as domestic auto makers began downsizing their cars and switching to lighter weight materials such as plastics and aluminum for bumpers and side trim in order to achieve better fuel efficiency and compete with the rising auto import trend. Nickel plating in plumbing and automobiles has matured and is not expected to exert as strong an influence on the future domestic demand requirements. However, one potential area for nickel plating growth is in steel cans.

Imports of stainless steel, particularly flat rolled, have also precipitated a decline in domestic nickel demand for use by the fabricated metals industry in producing cutlery and other equipment for use in commercial and institutional kitchens, hospitals, dairies, and chemical processing plants. However, this trend is expected to turn around as import quotas on stainless steel mill products allow the domestic industry to maintain some market share and profitability.

Contract Construction (SIC 1500, 1600, 1700)

Nickel is used in contract construction principally in two forms, alloy steel and stainless steel. Nickel-bearing alloy steel in structural shapes is used as support frames for storage tanks and bridges, and for the internal structure of some commercial and industrial buildings. Nickel-bearing stainless steel is used in construction for siding on building exteriors, outdoor and indoor stair railings, window frames, and for other corrosion-resistant decorative purposes.

The increased use of cement in the place of alloy steel in construction of bridges and multistory buildings has reduced the nickel demand requirements in those uses. In addition, lower priced imported stainless mill and fabricated intermediate metal products, for use in the interior and exterior designs of commercial and institutional buildings, have also contributed to the downward trend in domestic nickel requirements by the contract construction industry. While the influence of stainless imports is expected to decline, as productivity and competitiveness of the domestic steel industry increase, the substitution of cement is expected to continue, as savings result in building time when using precast versus in situ steel-reinforced cement. The commodity specialists have projected a continuation of the 1982 intensity of use estimate, although the intensity of use regression equation projects zero in 1985 and forward with statistical significance.

Chemical and Allied Products (SIC 2800)

End uses in this group include nickel as a catalyst in the hydrogeneration of edible fats and oils and as a mordant to fix dyes to fabrics. Domestic primary nickel demand has declined from 4,878 st in 1972 to 3,794 st in 1982 in each of these areas for various reasons. These reasons include changes in consumer tastes, technological development, and imports of finished products.

The downward trend of nickel consumption by the domestic chemical industry for the hydrogeneration of edible fats and oils has been caused by the joint influence of a change in consumer tastes from fatty and high-cholesterol foods to low-fat and low-cholesterol foods (where nickel-based catalysts are not used), and developments that allow for the recycling of the catalysts used in the hydrogeneration process.

The decline in nickel used as a mordant is the result of rising textile and apparel imports. The rising import levels have reduced the domestic industry's market share and associated production levels, thereby also reducing the raw material requirements.

While the downward demand trend is expected to continue in the hydrogeneration catalyst area, it is not expected to continue in the mordant area. Extension of apparel import limitations, enacted in the late 1970's and extended in the early 1980's, will tend to allow the domestic textile and apparel industries to retain market share and improve productivity through increased investment in the modernization of operations and other capital improvements, thereby increasing domestic requirement for nickel-based mordants.

The intensity of use in the chemical industry trended to an extremely low level in 1993 (0.008), which results in a consumption level of only 1,610 st for that year. This was rejected by the nickel specialists, who used the 1987 intensity of use of 0.021 for 1993, which results in a nickel tonnage of 3,810 st for consumption that year.

Machinery (Except Electrical) (SIC 3500)

The intensity of use for nickel consumed in this industry dropped 50% between 1972 and 1982, a stronger decrease than that for tonnage (36%). (See figure 11*A*.) This also is reflected in the continued decline in intensity and almost

[17]Primary reported consumption (excludes scrap) of domestic use of contained nickel. Distribution of data based upon BOM end-use data, Census of Manufacturers Shipment Report, industry estimates, and analyst's judgment. Sources: U.S. Bureau of Mines. Minerals Yearbook, various years. Chapter on Nickel. U.S. International Trade Administration (DOC).

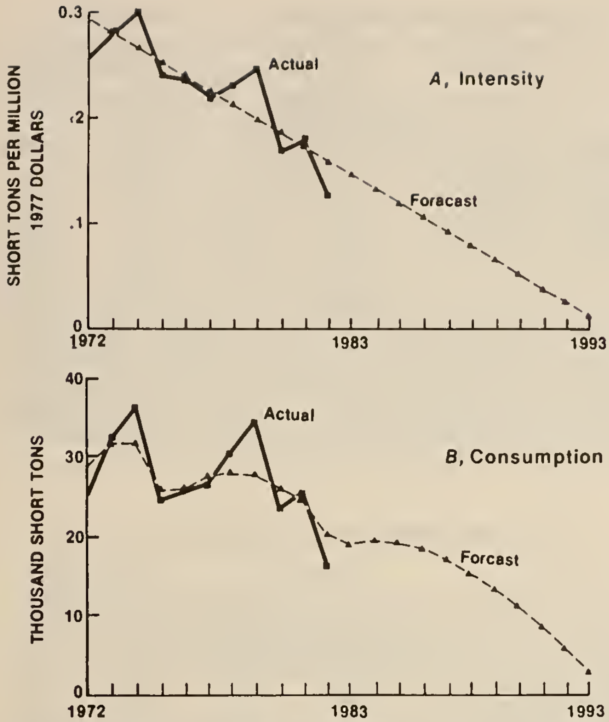

Figure 11.—Nickel intensity of use and consumption in nonelectric machinery, 1972-93.

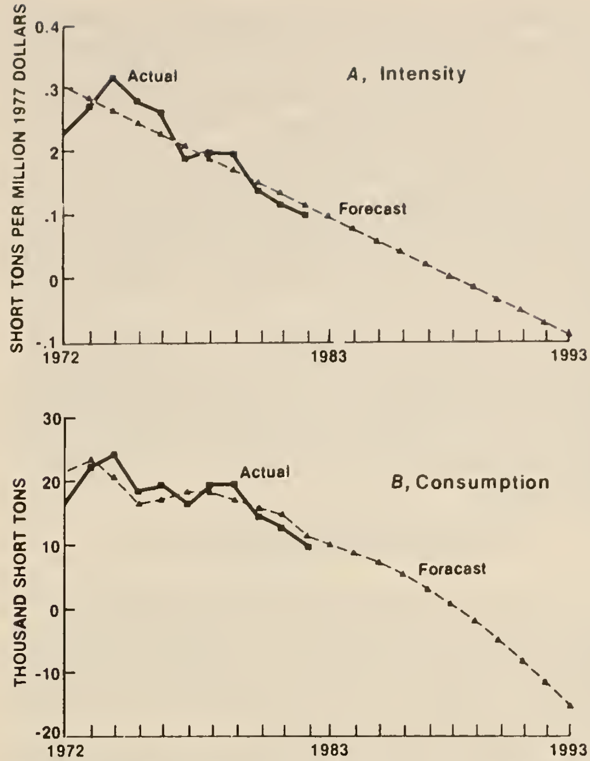

Figure 12.—Nickel intensity of use and consumption in electric and electronic equipment, 1972-93.

level consumption through the forecast period. The recent decade's diminishing nickel requirement must be weighed against earlier cycles, including the strong growth of the 1960's, in determining which movement to associate with future growth—a continuation of the present, or a new period in the cycle.

The primary reason for declining nickel content in machines is largely a result of the increased use of specialty steel in manufacturing processes. Also certain plated steels have adequate corrosion protection for many environments and are replacing the more expensive stainless steels. Nevertheless, it is unlikely the 1972-82 trend will continue, and consumption is expected instead to decline toward an asymptote not much lower than the 1987 projected tonnage of 16,806 st. (See figure 11*B*.) Therefore, the 1993 table 8 value is altered to show the substitute value.

Electric and Electronic Equipment (SIC 3600)

Intensity of use and consumption of nickel in this industry, based on data since 1972, show a 57% and a 42% drop, respectively, during the historical period, again reflecting a stronger decline in use of nickel than of the material in which it is used. (See figure 12.) The recent drop can probably be attributed in part to the slowed conversion to nuclear power-generating facilities in the late 1970's and early 1980's as well as to substitution of plastics for nickel in housing for electronic equipment. In the forecast period, the reduction continues to zero in 1989, despite the growth of electronic and electrical equipment at a rate of 5.3%/yr. There are several factors indicating that this will not result, and furthermore that the trend could reverse, including increased sophistication in power-generating and distribution equipment, innovations in the use of nickel powder alloys in transformers, and replacement of copper alloys with nickel alloys in lead frames for electronic circuit boards. The 1982 level of nearly 10,000 st, therefore, is assumed to be a floor below which electric equipment demand for nickel will not drop. The intensities shown in table 14 are the regression values for 1987 and 1993, even though these were not used to calculate the consumptions in table 8.

Transportation (SIC 3700)

The expected growth of nickel consumption for total transportation is distinct for each component of transportation: automotive, aircraft, and ships. The transportation industry, however, is not forecast as a high-growth sector by Chase Econometrics, and the use of nickel in transportation is projected to grow no faster than the industry itself, about 3.4%/yr.

The decrease in consumption from 1972 to 1982 in the automotive component reflects the trend toward lighter cars that contain less nickel product per unit value. Plating, which is a large nickel consumer, is decreasing as plastic replaces nickel in decorative components. Catalytic converters now contain smaller segments of stainless steel. Bumpers that contained nickel have shrunk continuously since the 1960's. Therefore, in spite of recent market improvements in the automotive industry, total consumption and the intensity have declined for nickel. Developments that may improve nickel intensity in the future include the introduction of nickel-plated terne sheets that could replace galvanized steel. A ferronickel product has also been developed to undercoat steel for subsequent chromium plating. Nickel consumption in the automotive component is likely to remain constant from 1987 onward because of these conflicting impacts on the nickel consumption ratio.

The intensity of nickel used in aircraft is also projected to be fairly constant. Although new nickel alloys, particularly some of the new powder alloys that have arrived in recent years, are well suited to the high-stress parts of aircraft jet engines, their small percentage of the total aircraft weight probably prevents significant changes in that ratio. The total consumption of nickel fluctuates in the aircraft based on the general economy, which governs the replacement contracts. Since the collective private air fleet is aging, total consumption is expected to increase and the ratio of nickel used to either remain the same or increase slightly.

The nickel uses in shipbuilding are increasing. A driving factor has been the Navy conversion to high-speed turbine engines and increased use of nickel in armor plating. The demand from the merchant fleet of ships should also increase over the next few years as ships begin to adopt copper-nickel sheathing as a protection against corrosion and barnacles.

PLATINUM-GROUP METALS

The platinum group consists of six metals that usually occur together in nature and are among the rarest of metallic elements: platinum, palladium, iridium, rhodium, ruthenium, and osmium. Platinum, palladium, and iridium are discussed below. The platinum group with gold and silver make up the precious metals.

From 1972 to 1982, total U.S. platinum consumption[18] rose at a compound annual growth rate of 3.4% (table 9); total palladium declined at a rate of 0.5%/yr (table 10); and total iridium dropped sharply at a compound annual rate of 11.0% (table 11). For most end uses of the platinum-group metals during this period, there have been declines in intensity of use as measured by the ratio of metal consumption to constant dollar industry output. (See tables 9-11.)

Although intensities are declining, consumptions are usually increasing, owing to growth in the industries consuming platinum, palladium, and iridium. In the forecast period 1983-93, total domestic platinum consumption is projected to grow at a compound rate of 3.9%/yr (table 9), total palladium is projected to rise at a rate of 1.6%/yr (table 10), and total iridium is projected to increase at a compound rate of 2.1%/yr (table 11).

Platinum, palladium, and iridium are each consumed in about 10 sectors in the U.S. economy (based on a 4-digit SIC level of disaggregation). In 1982, motor vehicle parts and accessories (i.e., catalysts for catalytic converters in cars) consumed 67% of all platinum, electrical uses and medical and dental equipment each consumed 35% of palladium usage, and electrical uses consumed 64% of all iridium.

Industrial Chemicals (SIC 2819, 2869)

A diverse group of chemicals is produced using platinum, palladium, and to a much lesser extent, iridium in chemical catalysts. A 90%-Pt catalyst is used to produce HNO_3 and HCN, which in turn are used to produce fertilizers, explosives, insecticides, plastics, and other chemical intermediates and in pickling stainless steels. Palladium

[18]Reported domestic consumption of primary and non-toll-refined secondary metal. Distribution based upon BOM end-use data, industry estimates, and analysts' estimates. Source: U.S. Bureau of Mines. Minerals Yearbooks, various years. Chapter on Platinum-Group Metals. U.S. International Trade Administration (DOC).

Table 9.—Iridium intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND TROY OUNCES PER MILLION 1977 DOLLARS				
Industrial chemical	0.40	0.03	*0.015	*0.015
Electrical and electronic	.18	.21	.13	.10
CONSUMPTION, THOUSAND TROY OUNCES				
Industrial chemicals	14,429	1,222	*801	*1,006
Electrical and electronic	4,042	6,789	*6,000	*6,000
Other[2]	19,283	3,589	4,407	7,550
Total	37,754	11,600	11,208	14,556

[1]These industries accounted for 76% of total iridium consumption in 1982.
[2]Iridium consumed in petroleum refining is included in "other" and in the total for 1972 and 1982, but is not included in forecasts for 1987 and 1993. This is a departure from tables 15 through 18 where platinum, palladium, and iridium are combined, both historically and for projections. The reason is that iridium consumed in petroleum refining declined from 17,284 troy ounces in 1972 to 1,111 troy ounces in 1982, and the 1987 and 1993 projections for the three metals (of which iridium is only a small part) are much greater than current iridium consumption for all uses.
*Subjective value selected over regression value.

Table 10.—Palladium intensity of use and consumption

Industry	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND TROY OUNCES PER MILLION 1977 DOLLARS				
Industrial chemicals	8.34	3.11	*1.16	*1.16
Petroleum refining[1]	1.78	0.52	0.79	0.37
Electrical and electronic	36.77	20.24	14.69	14.69
Motor vehicle parts and accessories	[2]4.36	4.43	5.58	6.16
Medical and dental equipment and supplies	*182.35	403.15	*282.92	*185.14
Jewelry and precious metals	10.59	6.84	8.26	6.65
CONSUMPTION, THOUSAND TROY OUNCES				
Industrial chemicals	303.816	132.649	*63.130	*79.225
Petroleum refining[1]	138.782	46.213	85.426	42.364
Electrical and electronic	443.503	321.973	*359.500	*450.263
Motor vehicle parts and accessories	[2]150.000	122.005	*189.447	*214.526
Medical and dental equipment and supplies	94.274	320.096	*344.000	*344.000
Jewelry and precious metals	19.375	8.109	*7.000	*7.000
Total[3]	999.750	951.045	1,048.503	1,137.378

[1]Includes platinum, palladium, and iridium.
[2]This is a 1974 figure, which is the first year palladium was consumed in this end use.
[3]Totals are somewhat overstated because the petroleum refining use includes platinum and iridium consumption, in addition to palladium consumption.
*Subjective value selected over regression value.

Table 11.—Platinum intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND TROY OUNCES PER MILLION 1977 DOLLARS				
Industrial chemicals	6.83	1.12	1.12	1.12
Petroleum refining[2]	1.78	.52	.79	.37
Electrical and electronic	3.91	2.52	2.29	1.61
Motor vehicle parts and accessories	[3]10.37	19.00	25.50	32.64
CONSUMPTION, THOUSAND TROY OUNCES				
Industrial chemicals	248.936	69.649	*61.352	*76.994
Petroleum[2]	138.782	46.213	*85.426	*42.364
Electrical and electronic	101.747	98.253	*121.944	*104.919
Motor vehicle parts and accessories	[3]356.522	523.569	*726.801	*823.012
Other	85.751	65.045	*138.902	*173.448
Total[4]	575.216	802.729	1,134.425	1,220.737

[1]These industries accounted for 92% of total platinum consumption in 1982.
[2]Includes platinum, palladium, and iridium.
[3]This is a 1974 figure, which is the first year platinum was consumed in this end use.
[4]Totals are slightly overstated because the petroleum refining use includes palladium and iridium consumption, in addition to platinum consumption.
*Subjective value selected over regression value.

catalysts are used to produce organic chemicals used in making paints, adhesives, rubber, and vitamins. Other PPI (platinum, palladium, iridium) catalysts are used in making synthetic fibers. Although demand for PPI in the chemical industry has declined since the early 1970's, this trend is expected to reverse as more demand is expected for chemical intermediates and, in turn, PPI. While new applications for PPI catalysts are found, recycling technology will continue to limit demand, which should grow at a low rate through the 1990's. Tables 9-11 illustrate this slow growth in consumption from 1987 to 1993.

Technological advances have increased the efficiency of recycling chemical catalysts. For example, a method for recapturing platinum (and rhodium) used in the production of HNO_3 has reduced metal catalyst losses. This increase in recycling efficiency is an important factor in the declines in intensity of use (both historically and projected to 1987) shown in tables 9-11.

Petroleum Refining (SIC 2911)

Catalysts containing PPI are used in a variety of petroleum refining reactions, principally for increasing the octane rating of fuel by reforming and hydrocracking. Since the early 1970's, demand for platinum and iridium catalysts in petroleum refining has decreased. One of the main reasons for this decline is that platinum and iridium are now dispersed in finer particle size (i.e., much thinner coating) in the reforming chamber. This increases catalytic efficiency because not only is less platinum and iridium used in the thinner coating, but also the finer particle size means a much larger surface area, thus making the catalyst more active (i.e., effective).

Demand for a palladium catalyst has increased since the early 1970's in its use in hydrocracking, a refining process that increases gasoline yields. Oil firms, wanting to produce more gasoline, since it is a relatively high valued petroleum product, have been adding hydrocracking equipment, and therefore also the palladium catalyst, to more of their refineries. In addition, the petroleum industry has been refining increasingly heavier grade crude oils, which yield less gasoline per barrel of crude than do lighter oils. To overcome this problem of an otherwise lower gasoline yield, more hydrocracking equipment, and in turn more palladium, is being used.

The demand for PPI in petroleum refining is expected to increase moderately through 1993, depending on the availablity and price of crude oil. The EPA has ordered a 90% cut in the lead content of gasoline by 1986, a factor that could boost PPI demand, particularly because the purpose of adding lead is to increase octane ratings. As with chemical catalysts, petroleum catalysts are highly recyclable; petroleum catalyst life has been progressively extended over the years, from a 5-yr life to as long as a 12-yr life (before recycling becomes necessary).

As shown in tables 9 and 10, the intensity of use for platinum and palladium declined in petroleum refining from 1972 to 1982, but is projected to increase until 1987 before declining again through 1993; the tables show a similar pattern for consumption. The projected decline in PPI consumed in petroleum refining from 1987 to 1993 might not occur. Substitution of other metals for PPI is unlikely because efficiency is a more important consideration in selecting a catalyst than is the cost of the metals used in this catalyst. The projected intensity of use ratios are difficult to evaluate, given the uncertainty of predicting the net effect of all the factors (discussed above) on each of three metals (PPI).

Electrical and Electronic (SIC 3622, 3661, 3679 and 3694)

PPI are used in electrical contacts, switches, and relays, as well as in electronic circuits containing thick and thin films, and in capacitors, thermocouples, and fuel cell anodes. From the 1970's to the present, platinum demand has remained somewhat static, palladium demand has recently been increasing, while iridium demand has declined. Demand for palladium, particularly in electronic applications, is expected to continue to show strong growth in the coming years, with strong growth expected for electronic defense systems, computers, and advanced satellite and communication systems. In addition, since palladium is less expensive than gold, it is expected to partially displace gold in some electrical and electronic uses. On the other hand, palladium's use in telephone switching equipment is being displaced in the U.S. market by solid-state (electronic circuitry) switching equipment.

Table 9 shows a declining intensity of use for platinum during the entire 1972-93 period in the electrical and electronic sector. Platinum consumption declined slightly from 1972 to 1982 and is projected to increase to 1987 before declining to near current levels in 1993. Both projections seem reasonable given the possibility of more substitution of platinum by other, less costly metals (alloys) and/or solid-state electronic circuitry.

Table 10 shows the intensity of use for palladium declining from 1972 to 1987, and then remaining constant to 1993. Palladium consumption, which decreased 27% from 1972 to 1982, is projected to rise 12% by 1987, and then increase another 25% by 1993. The 1987 and 1993 projections are consistent with the above discussion of palladium electrical and electronic uses.

Table 11 shows that iridium's intensity of use increased 17% from 1972 to 1982. Intensity is projected to decline by more than 50% and consumption to decline slightly, by 1993. Because iridium is more expensive than all platinum-group metals except rhodium, it can be expected that other platinum-group metals as well as other metals (alloys) will substitute for iridium whenever this is possible without sacrificing performance.

Motor Vehicle Parts and Accessories (SIC 3714)

Platinum and palladium are used in catalysts for emissions control of carbon monoxide and hydrocarbons in cars and light-duty trucks. Since the United States began using automotive catalysts in 1974, demand for platinum and palladium has been somewhat cyclical, but generally shows an increasing trend. This is in spite of the fact that less platinum and palladium are now used per car than in 1974. For example, in 1974, 0.5 tr oz Pt was used per catalytic converter, and this has been reduced 10-fold in a typical three-way automotive catalyst containing 0.05 tr oz Pt, 0.02 tr oz Pd, and 0.005 tr oz Rh. However, some additional platinum is needed for platinum oxygen sensors, which are used with three-way catalysts to control the air-fuel mixture of the carburetor.

The increased efficiency in using platinum-group metals for automotive catalysts is similar to that for petroleum refining discussed earlier. Platinum and palladium are now dispersed in finer particle size (i.e., much thinner coating)

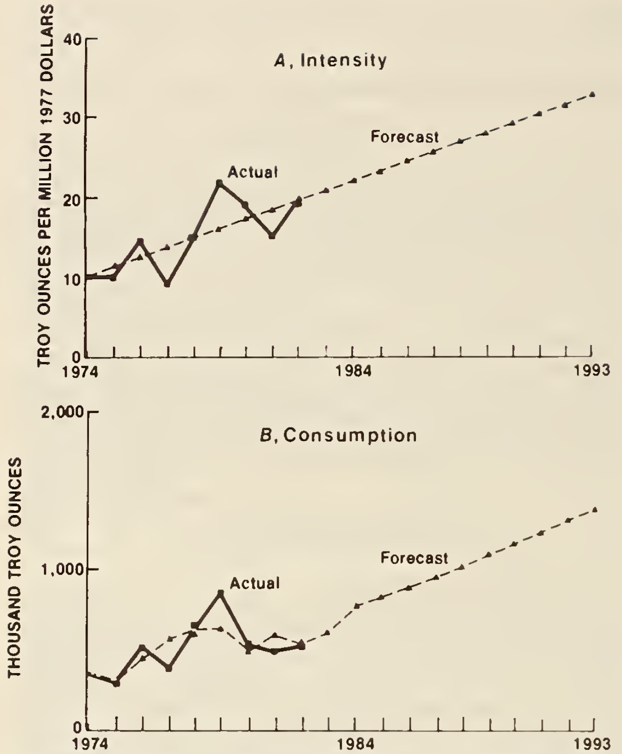

Figure 13.—Platinum intensity of use and consumption in motor vehicle parts and accessories, 1972-93.

in the catalytic converter. Not only is less platinum and palladium used in the thinner coating, but also the finer particle size means a much larger surface area, thus making the catalyst more active (i.e., effective).

The generally upward trend in platinum and palladium consumption since 1974 is expected to continue through the 1990's. EPA-mandated emission limits of noxious gases have not been stiffened since 1981, but some individual States have instituted mandatory annual emission testing in the last few years. In addition, there is the possibility that EPA will extend the guidelines of present emission levels to more trucks and possibly institute guidelines for diesel emissions.

Tables 9 shows both intensity of use and consumption of platinum in motor vehicle parts and accessories increasing throughout the 1974-93 period. This is in agreement with the above discussion.

Figure 13*A* shows the actual and estimated intensity of use ratios for platinum in motor vehicle parts and accessories. Figure 13*B* shows the actual and estimated platinum consumption for 1974-82 and 1974-93, respectively. A constant ratio was applied to calculate the projections, since the usual procedure would have resulted in consumption projections almost double the level thought to be reasonable. Advances in technology, i.e., efficient usage, considerably reduce the likelihood of continued rapid growth in platinum consumed in this end use.

Table 10 shows palladium's intensity of use increasing throughout the period 1974-93; however, it also shows palladium consumption declining from 1974 to 1982, and then increasing thereafter to 1993. The 1974-82 decline in palladium consumption reflects, in part, the increased efficiency in use of platinum-group metals discussed above.

Recycling of automotive catalysts, while more trouble than recycling petroleum and chemical catalysts, shows signs of growing rapidly.

Medical and Dental Equipment and Supplies (SIC 3843)

PPI are used in dentistry in crown and bridge alloys and alloys for porcelain veneers. PPI are used in medicine for electrodes in cardiac pacemakers and in medical compounds for the treatment of certain types of cancers. Since 1973, platinum demand has been relatively static, palladium demand has varied but generally increased, and iridium demand has been essentially insignificant. Demand for palladium in dental materials is expected to continue to increase but at a lower rate, particularly since other materials such as ceramics and/or other precious metals can be substituted.

As shown in table 10, the intensity of use ratio for palladium in dentistry and medicine more than doubled from 1972 to 1982, but it is projected to return to the 1972 level by 1993. Similarly, the volume of palladium consumed in this use more than tripled from 1972 to 1982. It is projected to increase only slightly from 1982 to 1987, and then level off to 1993.

The intensity of use ratio for platinum declines throughout the 1972 to 1993 period, and platinum consumption (roughly one-tenth as large as palladium consumption) also decreases from 1972 to 1993, interrupted only by a slight increase from 1982 to 1987. Iridium's intensity of use ratio and consumption volume had been declining from 1972 to 1982, but the ratio is projected to increase to 1987 and then level off to 1993; iridium consumption is expected to increase from 1982 to 1993, but remain insignificant. Platinum and iridium for dental and medical uses are included as part of the "Other" category in tables 9 and 11, respectively.

Medical uses of PPI are expected to grow quickly, but not consume large quantities of metal. Recycling is of minor importance to the dental and medical industry.

Jewelry and Precious Metals (SIC 3911)

PPI are used in jewelry for gem settings and decorative finishes. Demand since 1973 has remained static or declined somewhat over the last several years. No growth is expected to occur, and no change in American preference for gold in jewelry is anticipated. However, jewelry is subject to speculation, and this could result in cyclical swings in PPI consumption. Palladium consumed in jewelry is shown in table 10, and platinum and iridium consumption for this use are included as part of "Other" in tables 9 and 11, respectively.

TIN

From 1972 to 1982, U.S. primary tin consumption[19] decreased at a compound annual rate of 5.4%/yr, from 70,300 to 40,300 mt (fig. 14). However, the decline was not steady, and 4 of the 10 yr showed consumption increases. Since 1980 there has been a decline in tin usage as measured by the ratio of tin consumption to constant dollar industry output (intensity of use) for 22 of the 24 end-use sectors.

From 1982 to 1993 total domestic tin consumption is projected to continue declining, but at a compound annual rate of 3.2%/yr (table 12). Tin consumption in 24 industries

[19]U.S.-reported consumption of primary and secondary tin (includes scrap) in manufacturing products. BOM reports tin in metric rather than short tons. Distribution based upon BOM end-use data and analysts' estimate. Sources: U.S. Bureau of Mines. Minerals Yearbooks, various years. Chapter on Tin. U.S. International Trade Administration (DOC).

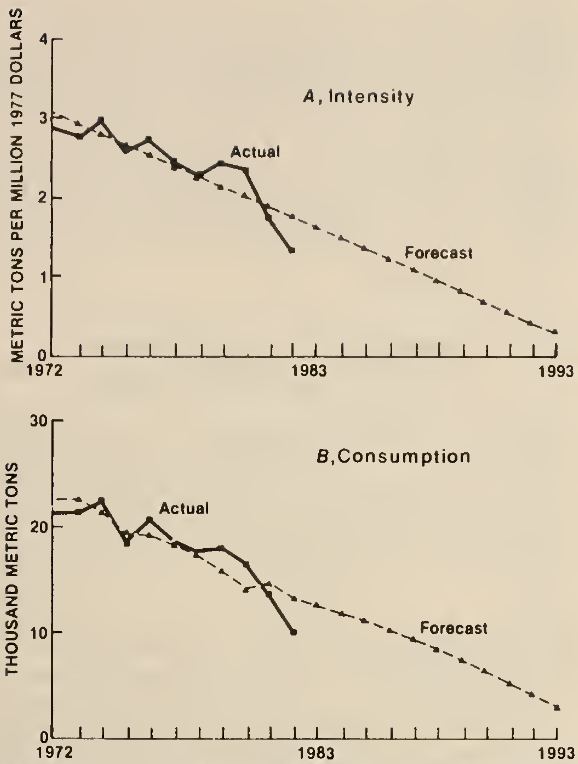

Figure 14.—Tin intensity of use and consumption in metal cans, 1972-93.

Table 12.—Tin intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, METRIC TONS PER MILLION 1977 DOLLARS				
Industrial chemicals	0.192	0.082	0.036	*0.015
Metal cans	3.87	1.33	1.08	**.500
Motor vehicles	.158	.117	.098	.080
Electronics	.466	.203	.098	0
Construction machinery and equipment	.137	.096	.099	.091
Valves, pipe fittings, metal foil and leaf, collapsible tubes	.204	.130	.142	.119
CONSUMPTION, METRIC TONS				
Industrial chemicals	7,010	3,489	1,961	*1,000
Metal cans	21,108	9,951	9,218	*4,831
Motor vehicles	8,879	5,014	6,168	5,944
Electronics	8,624	6,890	*6,269	*7,786
Construction machinery and equipment	1,360	929	1,255	1,566
Valves, pipe fittings, metal foil and leaf, collapsible tubes	2,165	1,738	2,438	2,563
Other	21,166	12,247	10,389	7,536
Total	70,312	40,258	37,698	31,226

[1]These industries accounted for 70% of total tin consumption in 1982.
*1989 value substituted for calculated value.
**1991 value substituted for calculated value.

in the U.S. economy based on a 4-digit SIC level of disaggregation were analyzed in this study. The largest use is metal cans, accounting for 25% of tin consumption in 1982; this was followed by electronics at 17%, motor vehicles at 12%, and industrial chemicals at 9%.

Industrial Chemicals (SIC 2819)

Tin is used in a variety of inorganic and organic chemicals. The largest tin organic compound use is as a stabilizer to produce polyvinyl chlorides (PVC), used to make plastic pipes, bottles, residential siding, and window frames. Other tin chemical uses include wood preservatives, marine (ship hull) antifoulants, and toothpaste additives.

The forecast for these rather specialized chemicals is more optimistic than the trend projections for 1987 and 1993. The least-squares estimate for 1993 was 0; however, according to industry specialists' judgment, use will not dip below the expected 1989 levels of 0.015 intensity and 1,000 mt consumption (presented in table 12). Over the past 30 yr, the most intensive research effort among all categories of tin consumption has been in the field of new uses for tin chemicals. Most of the Tin Research Institute's (the major tin research laboratory) efforts have been, and continue to be, in this area.

Metal Cans (SIC 3411)

Domestic tin consumption in this category essentially comprises the use of tinplate for cans and a small amount of solder for can joining purposes. Use of tin in this end-use has shown a fairly steady decline over the past 15 yr due to two main causes: (1) the inroads of aluminum in the beverage can market (tinplate still overwhelmingly holds the food can market); and (2) use of thinner tin coatings on steel by tinplate producers (i.e., the large steel firms). These causes will be less important in the future since there is little tin left in the beverage can market to be displaced, and tin coatings cannot be made much thinner without sacrificing corrosion resistance.

Tinplate also faces competition in the container sector from glass, plastics, and composites (i.e., the cardboard bodies of frozen juice cans). Aluminum has over 90% of the beverage can market, but only 4% of the food can market. The penetration of aluminum into the food can market, if it occurs, is expected to be a relatively slow process because of uncertainties regarding price relationships between aluminum and tinplated steel coupled with capital costs associated with such a conversion. Technical problems associated with aluminum can sidewall strength would also have to be solved. (See "Aluminum, Metal Cans" section for more detail.)

This gradual decline of tin use in metal cans (now food cans) is consistent with the 1987 projection, which shows a 7.4% decrease in consumption compared with 1982 data (table 12); the intensity of use shows an 18.8% drop during these 5 yr. However, for the period from 1987-93, table 12 shows much greater declines of about 50% for both tin consumption and intensity of use in this sector. This decline was adjusted upwards from a zero projection shown in figure 14, to levels reached several years earlier. For the reasons stated above (and in more detail in the "Aluminum" section), the adjusted consumption and intensity of use from 1987 to 1993 (shown in table 12) may also be low estimates; i.e., the 1993 projections appear to overestimate how quickly, if at all, aluminum will replace tinplate in the food can market.

Motor Vehicles (SIC 3711)

Tin consumption in this category consists of three main uses: (1) tin-lead solder for body filler, used for joining structural members, (2) solder for joining and subsequently repairing radiators, and (3) solder for joining circuitry in the vehicle. The first use has declined over the past 10 yr as cars have become smaller and as car makers have sought to eliminate lead from the workplace by instead using welded joints. The second use has decreased slightly as cars (and thus radiators) have become smaller and by the introduction of aluminum radiators, which do not use solder. Solder for radios, electronic ignitions, and other controls in

cars is the smallest of the three main uses, but is growing rapidly.

It is expected that the first use will continue to decline, but the second use may remain constant since there have been problems fabricating and installing aluminum radiators and there are also some indications that new solder techniques could be used to repair them. Tin use in car electronics is expected to continue to grow.

The above discussion is consistent with table 12, which shows tin use in motor vehicles increasing 23% from 1982 to 1987 and then declining slightly in 1993. Intensity is declining throughout the 1972-93 period.

Electronics (SIC 3621, 3622, 3651, 3674, 3679)

In the electronics sector (primarily radio and TV sets, industrial controls, and semiconductors) intensity of use has declined substantially, as shown in table 12. There are two primary reasons for the decline. First, the use of printed circuit boards and solid state devices has reduced the amount of solder used in a single electronic device. Second, miniaturization has reduced the size of electronic components and, therefore, per unit consumption of tin.

Table 12 shows that the volume of tin consumed in electronics declined 20% from 1972 to 1982, is predicted to fall another 9% by 1987, and is then projected to rise 24% in the 1987-93 period. The decline in tin used per unit of electronics equipment is being offset by the rapid growth of the electronics sector, which is one of the fastest (if not the single fastest) growing areas in the economy. The total consumption forecast was calculated as a regression on the end use, rather than an intensity regression on time.

Construction Machinery and Equipment (SIC 3531)

Tin intensity of use in construction machinery and equipment declined 30% from 1972 to 1982, as shown in table 12. This decline is primarily the result of improved assembly techniques, which reduce soldering, and the substitution of tin by other alloys. From 1982 through 1993 the intensity of use for this category is projected to remain relatively constant. The volume of tin consumption, which had declined 32% in the 1972-82 period, is projected to increase 69% from 1982 to 1993, as table 12 illustrates. The increase is totally a function of increased demand for construction machinery and equipment.

Valves, Pipe Fittings, Metal Foil and Leaf, Collapsible Tubes (SIC 3499, 3497, 3494)

In these uses, consumption has declined primarily because of substitution by other alloys, such as copper and aluminum. Plastic toothpaste pumps and tubes have substituted for tin toothpaste dispensing tubes. Tin consumption for this category is anticipated to remain relatively stable through the early 1990's. Table 12 shows the intensity of use decreasing slightly during the actual and forecast periods. The volume of tin consumption is projected to increase only slightly as the industry output increases, because of the intensity continuing in the other direction.

TITANIUM

The average annual growth in titanium demand for 1972-82 was nearly 8%, even though there were severe slumps in 1975, 1976, and 1982. Only two industries were analyzed: aircraft industry use (70% in 1982) and all uses not associated with the aircraft industry (table 13). The aircraft industry intensity, the ratio of titanium consumption[20] to constant dollar value of shipments for aircraft engines and aircraft parts, declined slightly from 1972, after peaking at more than 80% above the 1972 level in 1974 and 1981 (fig. 15).

Commercial production of titanium metal began in the early 1950's. Because of the high strength-to-weight ratio of its alloys and their resistance to corrosion, titanium is an important strategic, critical material, and is widely used for high performance in military and civilian aircraft in both airframes and engines, in surface condensers for powerplants, and for a wide variety of chemical processing

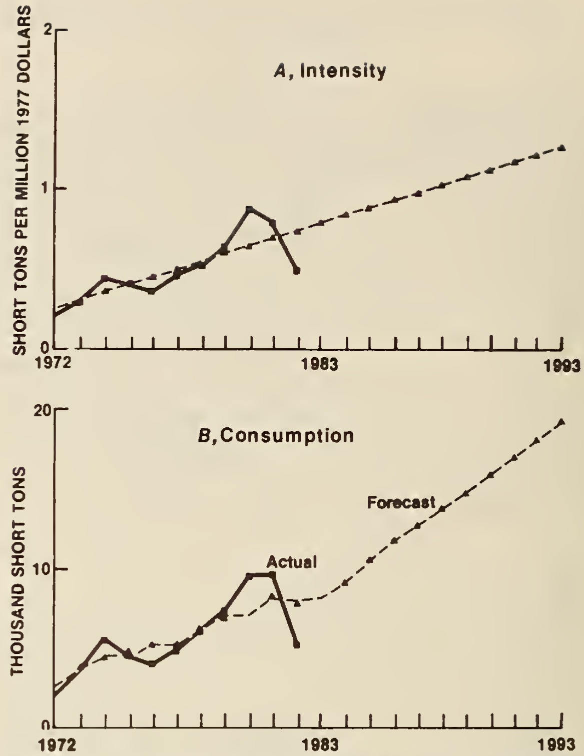

Figure 15.—Titanium intensity of use and consumption in fabricated plate work and special industrial machinery, 1972-93.

Table 13.—Titanium sponge metal intensity of use and consumption

Industry	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, SHORT TONS PER MILLION 1977 DOLLARS				
Aircraft engines, engine parts, and auxiliary equipment	0.78	0.77	1.10	1.15
Fabricated plate work and special industrial machinery, n.e.c.	.20	.49	.97	1.26
CONSUMPTION, SHORT TONS				
Aircraft engines, engine parts, and auxiliary equipment	10,978	12,130	16,042	*21,000
Fabricated plate work and special industrial machinery, n.e.c.	2,091	5,198	*7,000	*10,000
Total	13,069	17,328	23,042	31,000

*Subjective value selected over regression value.

[20]Consumption of reported titanium sponge. Data description based upon BOM end-use data, industry estimates, and analysts' judgment. Source: U.S. Bureau of Mines. Minerals Yearbooks, various years. Chapter on Titanium. U.S. International Trade Administration (DOC).

and handling equipment. In 1983, about 75% of titanium consumption was for aerospace applications. The titanium industry has been periodically subject to wide fluctuations in demand caused by abrupt changes in requirements for both military and commercial aircraft programs.

The titanium intensity of use in nonaerospace applications (fabricated plate work and special industry machinery, n.e.c.) increased substantially, peaking at over four times the 1972 value in 1980, and was still over double the 1972 value in 1982.

Aircraft Engines, Engine Parts, Auxiliary Equipment (SIC 3728)

The aircraft industry consumption pattern is extremely erratic during this period. Increases and decreases of 30% to 40% in titanium consumption occurred in 4 yr out of 9, and the direction of movement is frequently opposite that of aircraft industry output. Intensities do not follow a trend, making it difficult to use this method for developing projections.

The upward trend in the ratios of titanium consumption to shipments in the aircraft industry is not statistically significant but is nevertheless perceived as the correct direction, based on the judgment of the commodity specialists. This trend is expected to continue through 1993 (table 13). Higher titanium demand should result from increasing requirements for high-performance military aircraft, and from aircraft industry plans to replace aging airliner fleets with lighter, more fuel-efficient planes with a larger proportion of titanium than current models. It is expected that significant replacement of titanium by composites will not occur by 1993. Titanium is very compatible with composites because of its matching coefficient of thermal expansion and high corrosion resistance, making it a preferred material for attaching composite parts being used to replace other materials, particularly aluminum. The statistically calculated projection for titanium consumption in 1993 using the intensity projection is only 15,000 st, which was judged too low to fill the needs of the aircraft industry; a more reasonable forecast is 21,000 st, which represents a 5%/yr growth rate during the 1972-82 period.

Fabricated Plate Work and Special Industrial Machinery, n.e.c. (SIC 3443, 3559)

Because of its corrosion resistance and high strength, titanium is likely to be increasingly used for applications in the electric utility, chemical processing, pulp and paper, oil refining, water desalinization, and other industries. A projection of titanium intensity of use for these applications doubled in 1987, then increased less rapidly through 1993, which was considered unrealistic. (See figure 15*A*.) The resulting projected consumption of 19,000 st in 1993, a growth rate of 9.2%/yr from 1982, is much higher than seems likely based on industry estimates. The forecast was adjusted downward to 7,000 st for this application in 1987, and 10,000 st in 1993, which represents a growth rate of 6.1% from 1982's estimated trend value. (See figure 15*B* and table 13.)

Based on growth rates of 4.9%/yr and 6.1%/yr for aerospace and other industrial applications, respectively, from 1982 historical trend values, consumption of titanium in 1993 is expected to total 31,000 st, 72% higher than the values for 1982.

Table 14.—Tungsten intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, THOUSAND POUNDS PER MILLION 1977 DOLLARS				
Machine tool accessories, metal cutting accessories, metalworking machinery	0.33	0.48	0.56	0.64
Construction machinery	.10	.15	.18	.21
Mining machinery	.59	.74	1.07	1.28
Oil field machinery	.54	.36	.29	.18
Electrical equipment and supplies, n.e.c.,	2.31	2.05	2.47	2.02
CONSUMPTION, THOUSAND POUNDS				
Machine tool accessories, metal cutting accessories, metalworking machinery	3,109	4,074	6,636	8,226
Construction machinery	983	1,415	2,271	3,653
Mining machinery	905	1,313	2,342	3,304
Oil field machinery	1,118	1,522	1,396	1,076
Electrical equipment and supplies, n.e.c.,	1,800	1,202	1,893	1,809
Other	5,381	4,471	6,675	8,177
Total	13,296	13,997	21,213	26,245

[1]These industries accounted for 68% of total tungsten consumption in 1982.

TUNGSTEN

Tungsten's unique, high-temperature properties account for its increased demand, particularly in the major end use forms of carbide and pure metal. It is one of the few metals with increasing intensity of use. This characteristic, combined with the fact that it is consumed primarily in high-growth industries, led to a projected growth nearly double the current level by 1993[21].

In the 1972-82 period, intensity of use increased in 11 of the 21 industries tested; these industries accounted for 51% of the tungsten consumed in 1982. Therefore, the total consumption is growing. Some declining uses, for example, blast furnaces and steel mills, have kept the consumption level fairly constant during this period, but will not continue to do so in the forecast period. By 1987 tungsten consumption is expected to increase 52% over its 1982 level (table 14). One-third of this volume will have come from tungsten used in metalworking machinery and tools.

Machine Tool Accessories, Metal Cutting Accessories, Metalworking Machinery (SIC 3549, 3545, 3541)

Metalworking machinery, machine tool accessories, and cutting tools (considered for the purpose of this report as one industry) is the largest end use industry for tungsten, primarily in the form of carbides. The ratio of tungsten consumption to constant dollar industry output increased during the 1970's and is expected to continue growing during the 1980's and early 1990's. (See figure 16.) However, the growth rate is expected to decline as coatings continue to improve the cutting and wear resistance of cemented carbide tool inserts, and as substitutes, such as aluminum oxide, cermets, and other materials, erode tungsten's market share. The use of tungsten in this market is growing not only as a result of increased intensity, but even more owing to the growth of the industry itself. The 3.5%/yr growth of metalworking machinery and tools will keep the tungsten demand high even when intensity growth has leveled.

[21]Primary products consumption of contained tungsten (includes scrap). Data distribution was based upon BOM end-use data and analyst estimates. Sources: U.S. Bureau of Mines. Minerals Yearbooks, various years. Chapter on Tungsten. U.S. Federal Emergency Management Agency.

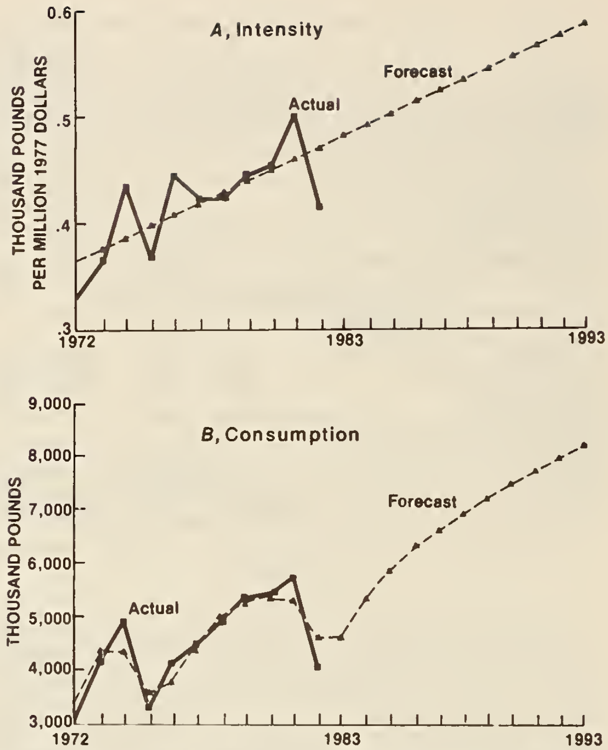

Figure 16.—Tungsten intensity of use and consumption in metalworking machinery, 1972-93.

Construction Machinery, Mining Machinery, Oil Field Machinery (SIC 3531, 3532, 3533)

Construction and mining machinery, two of tungsten's largest consuming industries, have been and will continue using increasing amounts of tungsten, primarily in the form of cemented carbides to improve machinery productivity.

Although oil field machinery use of tungsten has increased in each year except the 1975 and 1982 recessions, the intensity of use had declined because tungsten consumption did not grow as fast as oil field machinery output, a very fast growing sector in the 1970's, even before the OPEC price increase. Omitting the depressed 1982 figures, the compound growth rate for tungsten was 7.8%/yr, but that of oil field machinery was 9.8%/yr. Oil field machinery is not expected to continue growing at that high rate, but will fall back to only 2.9%/yr. This has the effect of reducing tungsten consumption slightly, when coupled with the decreasing intensity.

Like metalworking machinery, the construction and mining machinery industries' use of tungsten benefits from both industry growth and growing intensity of use within those industries. Combined, the projected increase is 6.8%/yr growth.

Electrical Equipment and Supplies, n.e.c. (SIC 3699)

Electrical equipment and supplies' demand for tungsten is another large end use sector and follows the usual unpredictable pattern of tungsten consumption. The tonnage figure changed direction during the historical period more often than it continues in the same direction. Furthermore, the movements of tungsten volume do not match the movements in user industry volume, reducing the value of the intensity calculation. There is a downward trend, in spite of some very large increases. The 1970's downward trend primarily reflects the growing use of solid state ignition systems, which replaced tungsten contact points in automobiles. Indications are that tungsten usage per unit of output will remain virtually unchanged through the 1980's and 1990's.

Other

Three other tungsten end use consuming industries are worthy of note—X-ray shielding, ammunition, and industrial inorganic chemicals. The use of tungsten as a catalyst for use in the chemicals industry and as a metal for X-ray shielding could substantially increase; conversely, the use of tungsten for ammunition is being replaced by depleted uranium. Thus, the ratio of tungsten consumption to output in the former industries is expected to substantially increase during the late 1980's and early 1990's but is expected to substantially decline in the latter 1990's.

ZINC

Total U.S. slab zinc consumption[22] decreased by almost half from 1972 to 1982, falling from 1.4 million st to 781,248 st (table 15). This represents a decline of 6%/yr at a compound rate, due in part to recessions in the construction and motor vehicle industries in 1982 and to a decrease in zinc consumed by the cutlery, handtools, and hardware sectors. Similarly, from 1972 to 1982 there was a decline in zinc's intensity of use (ratio of zinc consumption to constant-dollar industry output) for all major end uses except construction.

Domestic zinc consumption is projected to reach 842,100 st in 1993. The actual rise in total slab zinc consumption to 888,000 st in 1983 and to 936,000 st in 1984 would have tempered the intensity decline, had these data been included in the estimation. Their presence would not have

[22]Slab zinc consumption. Distribution of data based upon Bureau of Mines, the American Iron and Steel Institute, the Zinc Institute, and analyst estimates. Sources: U.S. Bureau of Mines. Minerals Yearbooks, various years. Chapter on Zinc. U.S. International Trade Administration (DOC).

Table 15.—Slab zinc intensity of use and consumption

Industry[1]	Actual 1972	Actual 1982	Forecast 1987	Forecast 1993
INTENSITY OF USE, SHORT TONS PER MILLION 1977 DOLLARS				
Construction:				
general	0.0013	0.0014	0.0016	0.0017
highway	.0006	.0006	.0007	.0008
heavy	.0013	.0015	.0018	.0020
Motor vehicles and equipment	.0040	.0024	.0012	.0002
Air conditioning and heating	.0044	.0031	.0024	.0016
Heating equipment and plumbing fixtures	.0117	.0072	.0057	.0033
Cutlery, handtools, and hardware	.0200	.0088	.0028	*.0018
CONSUMPTION, THOUSAND SHORT TONS				
Construction:				
general	130.87	95.01	141.04	168.87
highway	63.97	42.57	64.68	74.88
heavy	135.71	107.61	161.05	194.93
Motor vehicles and equipment	372.79	180.53	**264.29	**312.07
Air conditioning and heating	38.12	26.97	26.13	21.25
Heating equipment and plumbing fixtures	34.60	20.88	22.39	14.9
Cutlery, handtools, and hardware	147.85	57.92	25.78	**19.78
Other	494.49	250.66	111.66	35.42
Total	1,418.40	781.25	817.02	842.10

[1]These industries accounted for 68% of total slab zinc consumption in 1982.
*1988 intensity ratio.
**Subjective value selected over regression value.

changed the direction, however, of a downward trend. Increasing zinc demand for galvanizing steel in the motor vehicles and construction sectors is expected to offset continued long-term decreases in both consumption and intensity of use of zinc in most other end-use sectors.

Slab zinc consumption was analyzed in 35 industries in the U.S. economy based on a 4-digit SIC level of disaggregation. The largest use was construction, accounting for 31% of zinc consumption in 1982, followed by motor vehicles and parts at 23%, and cutlery, handtools, and hardware at 8%. In the construction and motor vehicle industries, zinc coatings (galvanizing) provide corrosion protection to steel. Zinc die-cast parts are used by motor vehicles and by the appliances and machinery sectors. Brass (copper alloyed with zinc) is used in builders hardware, consumer goods, and electrical parts.

Construction (SIC 1500, 1610, 1620)

Consumption of zinc in the construction sector represents the largest use of zinc in the United States. This sector includes general, highway, and heavy construction. Zinc in these end-use sectors is used predominantly as a protective coating material in galvanized sheet, wire, tubes, and fittings. A small amount is consumed as rolled zinc. The consumption of zinc in construction declined from 1972 to 1982, mostly because of a long-term downtrend in new construction activity. In fact, total construction expenditures declined by one-third during this period.

During the 10-yr forecast period, zinc consumption in the construction sector is projected to rise to 439,000 st in 1993. A slight increase in the intensity of zinc usage is expected, and a projected turnaround in construction activity will result in increased zinc consumption in this sector through 1993. Today's marketplace has become more aware of the benefits gained by using zinc coatings for corrosion protection. In addition, there is no economic substitute for zinc that provides the same quality and durability. These factors should lead to increased zinc consumption in the future.

Motor Vehicles and Equipment (SIC 3710)

This end-use category includes automobile, truck, and bus manufactures. The largest area of zinc use in the category is in automobile production, where zinc is used as zinc die-cast parts such as grills, handles, and locks; as brass items such as radiators, tubing, and electrical fittings; and as zinc coating on steel to provide corrosion protection. Zinc used in tire production, which requires about 0.5 lb ZnO per tire, is not included.

The domestic automobile manufacturing sector underwent several fundamental changes since 1972 that affected the course of zinc usage in vehicles. The principal change in zinc demand per automobile was initiated by the "oil crisis" of 1973-74, which set off large-scale downsizing and weight reduction programs that reduced the amount of zinc diecastings as well as brass used in cars. The reduction was carried out by substituting aluminum and plastics for zinc, elimination of parts, and using thin-wall zinc diecastings, which require less zinc than previously required in traditional diecastings. In 1975, about 51 lb of zinc diecastings were used in the average domestically built automobile; this declined to an average of 23 lb per automobile in 1983. Another major factor affecting zinc demand in this sector was automobile imports and their effect on domestic output of automobiles. Domestic manufacturers, unable to compete in the small, fuel-efficient, automobile segment of the market, lost market share and produced fewer units. In summary, zinc consumption in the domestic automotive sector fell owing to downsizing and weight reduction programs, substitution for and elimination of zinc die-cast parts, and production of fewer automobiles in the 1972-82 period.

The forecast of intensity of use is that the trend will continue decreasing, even when the 1983 upturn is included. However, more recent data and automotive industry plans for future zinc use would indicate more usage in the forecast period. The decline in the weight of zinc diecastings per automobile appears to have leveled out in 1983 and rose slightly in 1984. Also, in recent years consumer concern for longer lasting automobiles, coupled with fierce import competition, has resulted in a stronger emphasis on corrosion protection by automobile manufacturers. Zinc coating usage for corrosion protection of steel underbody parts has increased significantly in recent years and is planned to increase further in the next few years. An annual survey of the top four domestic automakers indicated that the average 1984 model car contained 7.15 lb Zn in coatings compared with 6.59 lb Zn in the average 1982 model car. In response to 5-yr rust protection warranties, auto manufacturers plan to order increasing amounts of zinc precoated steel for the 1986 and future model automobiles. The same trend is taking place in the manufacture of trucks and buses. To provide the necessary protection, the previously uncoated outer surfaces of exterior panels such as fenders and doors will be zinc coated mainly by electrogalvanizing. To meet the expected electrogalvanizing sheet demand, steel companies have and are increasing their electrogalvanizing capacity.

In summary, zinc demand in this sector is expected to increase despite 10 yr of declining use; therefore, the projected trends have not been used in the tables. Instead, the projections use the 1983 intensity of use ratio extended through the forecast period, giving what is thought by the

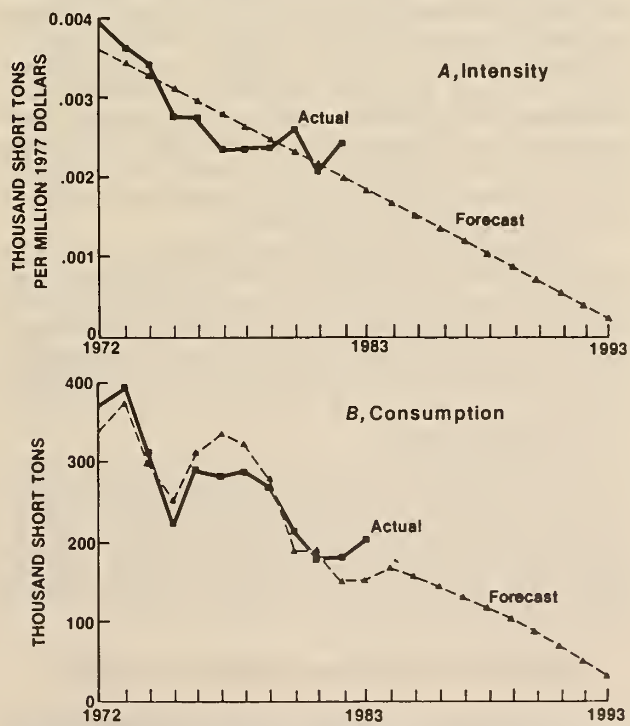

Figure 17.—Zinc intensity of use and consumption in motor vehicle parts and accessories, 1972-93.

experts to be a more realistic estimate. It is possible the adjustment is high, but raised levels of zinc consumption in 1983 and 1984 (not included in the data base) could not have been predicted by the estimated equation.

Figure 17*A* shows that for motor vehicles and parts, zinc's intensity of use has been relatively constant since 1977, with the exception of 1980-81. Because of declines in the earlier years 1972-76, the trend line projected to 1993 is downward. Figure 17*B* shows zinc consumption for the 1972-83 actual tonnage, and a forecast resulting from applying the 1983 ratio to industry output. The constant (1983) ratio forecast was chosen because, as discussed above, the outlook for zinc in this end use is optimistic.

Air Conditioning and Heating (SIC 3585)

Another large consuming sector of zinc is the air conditioning and heating sector. Zinc in this sector is consumed predominantly in galvanized sheet and tubes, with lesser amounts in brass sheet, tube, and zinc die-cast parts. The historic long-term trend of zinc usage in this sector is decidedly downward, declining by one-third over the 1972-82 period. The forecast for this end-use sector reveals continued declining intensity of use and consumption. This projection assumes no fundamental change in historic demand factors. Thus, the moderate decline in actual consumption could stabilize at current levels or increase slightly if market factors are altered. An example of this is the future mix of single unit versus multiunit residential dwellings, with strong demand for multiunit dwellings resulting in strong demand for air conditioning and heating equipment.

Heating Equipment and Plumbing Fixtures (SIC 3430)

Zinc is consumed in this sector mostly as brass rod and castings, with minor amounts of other diecastings and galvanized products. Finished goods in this sector include drains and faucets, traps, and other brass goods, and cast components in air heaters and furnaces.

Zinc consumption in this sector has experienced a fluctuating long-term decline. This was due to material substitution and to thin-wall die-cast parts in plumbing and heating applications. While this downtrend is projected to continue, it is expected to be at a much reduced rate since the substitution of zinc by other materials appears to have abated. In fact, the 1993 projection may represent the low end of zinc consumption in this sector. Zinc consumption in plumbing and heating may very well remain steady or increase slightly given the expected turnaround in the construction sector.

Other

Of the remaining 28 sectors, 18 projected zero consumption before 1993. Although this is not a probable consumption level in most cases, the individual forecasts were not altered and their total, 111,000 st in 1987 and only 35,000 st in 1993, is probably erroneously low. The zinc specialist pointed out the 1993 "Other" tonnage might be accounted for by zinc penny use alone.

CONCLUSIONS

The analyses of changing intensities of use have shown that for the historical period, 1972-82, structural changes occurred in an overwhelming majority of end uses for all 12 metals. Chromium, cobalt, copper, lead, manganese, nickel, tin, and zinc are experiencing declining use. Aluminum, the platinum-group metals, titanium, and tungsten exhibited consumption growth. Out of 232 regressions run, 188, or 81%, of all 12 metals' end uses had decreasing intensities; for chromium, manganese, lead, and tin, the percentages were over 90%.

Although it is possible for consumption to grow in an opposite direction from intensity of use, when end use product growth is strong but contains less of the metal per unit of product, this has not often been observed in this historical period. It is expected to occur more often in the forecast period, however, when economic growth in user industries is expected to continue to be as strong as or stronger than that of 1983 and 1984.

If intensity of use had been measured as consumption per capita or consumption per million dollars of real GNP, all metals in the study except titanium would be seen to have declined. Total U.S. nonferrous metal consumption per million dollars real GNP declined 49.2% between 1972 and 1982, and nonferrous metal consumption per capita declined 37.2% in the same period.

FACTORS AFFECTING INTENSITY OF USE

An event of singular importance in effecting changes in metal requirements was the first and major OPEC price increase in late 1973. The effects on the energy-intensive mineral industry were strongest in 1975. The 1975 reduction in consumption, averaged over all 12 metals, was 30.5%.

Total consumption for each metal shows a major dip in 1975. Only aluminum, the platinum group, titanium, and tungsten have recovered from the 1975 decline. Intensity of use and consumption of other metals began recoveries in 1976 and continued to improve until 1979, when the second major oil price increase caused another drop in metal demand. With the onset of the 1981-82 recession, metal industries were already in a decline, further compounding their problems. The average 1982 reduction in consumption for the 12 metals was 27.2%.

The industries that consume metals recovered more rapidly than did the metal industry. This is verified by the decreasing intensity of use ratios, in which the consuming industry output (denominator) grew faster than metal consumption (numerator). The consuming industries reduced costs by effecting production efficiencies, material substitutions, and product design changes that reduced the metal content of their products. The metal industries had one additional major production cost imposed during this period, that of pollution abatement.

This technological change effect on metal reduction is intensified by the slow, steady change in the composition of GNP. Although manufacturing has remained a fairly steady component over time, the real growth is in services, utilities, trade, finance, insurance, and the other components with low metal requirement. Both metal mining and primary metals have negative growth.

A third factor influencing decline in metal consumption

by U.S. manufacturers is the increasing integration and competition in the world economy. As a result, the United States imports not only raw products and final goods, but intermediate goods as well, thereby reducing demand for the comparable domestically produced goods. Metal demand is a function of its intensity of use in its own immediate markets, as well as the intensity of use of those goods in their markets. For example, manganese consumption in domestically manufactured machinery is a function of the reduced per unit requirement of manganese in steel, the reduced per unit requirement for steel in machinery, the imports of both steel and machinery, and the imports of goods that machinery might have produced domestically.

RELATED STUDIES

Several projects planned by the Bureau of Mines should enhance knowledge of structural change in the metal industry. The first, already in progress, is a measure of intensity of use changes in other countries for a group of metals including steel. This study will attempt to quantify causes for change over time and to derive a mathematical expression of total change as a function of its major causes. A second study uses input-output analysis to measure technological change and the effects of variation in final demand distribution.

APPENDIX.—EQUATIONS

The following tables are the equations estimated by ordinary least-squares regressions over the 1972-82 (or some cases 1972-83) time series. The econometric software package used is ESP from the Alpha Software Corp. of Burlington, MA, in conjunction with the Mikros Corp. Each table is a listing of equations for the metal identified at the top, listing selected end uses of that metal.

The equations add an analytical dimension that cannot be observed in the tables of the main text, where only two points each in real time and forecast time are shown. The equations show that nearly every major user of metals has a negative slope in the intensity equation; i.e., industries are using less metal per unit of output in each succeeding time period. The strength of the movement is shown in the R-square column, where many equations have an R-square larger than 0.8, quite a strong correlation between lower use and time.

In each case the dependent variable is the ratio of metal consumption to industry output, and the only independent variable is time. The equation is

$$x/y = a + bt,$$

where

x = volume of metal consumed in each year, measured in the unit indicated, by a particular industry;

y = value of industrial output in each year in the identified industry, measured in constant 1977 dollars;

a = the estimated intercept is shown with its calculated T statistic in parentheses. For 10 degrees of freedom, T = 1.81 is significant at the 95% confidence level.

b = the estimated slope, or coefficient of time in the equation. The slope is also interpreted as statistically significant when T = 1.81. A negative slope indicates a decreasing use of metal per unit of industry output, and a positive slope, an increasing use.

t = time in years, where t = 1 represents 1972, t = 2 is 1973, etc.

R square = the estimated degree of linear association between x/y and time, sometimes interpreted as the percentage of change in x/y "explained" by the time variable.

Since the y series, the industrial outputs expressed in constant dollars, are forecast by Chase Econometrics through 1993, the x volumes of metal may also be forecast, using the estimated equations, for any time period between 1982 and 1993:

x forecast = y forecast times (x/y) regression estimated in t

The column labeled SIC indicates the standard industrial classification, at the given level of aggregation, of the end-use industry. The equations are given for each metal in alphabetical order.

Table A-1.—Aluminum equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Metal cans	3411	0.05874	0.0130341	0.98
Sheet metal work	3444	.10777	−.00276	.70
Electric and electronic equipment.	3600	−.008121 (−.000314)	−21.155 (−6.02661)	.78
Motor vehicle bodies, parts, accessories.	3711, 3714	.00556 (25.664)	.000143 (4.87756)	.70
Transportation equipment.	3721, 3724, 3728, 3731, 3732, 3743, 3751, 3761, 3764, 3769, 3792, 3795, 3799	.00659 (−.00016)	13.7301 (−2.475)	.38

[1]Dependent variable: Thousand short tons of aluminum per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-2.—Chromium equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Chemicals industry	2800	0.00093 (14.102)	−0.0000215 (−2.405)	0.37
Refractory industry	3297	.12798 (16.745)	−.0086679 (−8.348)	.87
Fabricated metal products	3400	.000615 (12.183)	−.000021 (−3.066)	.48
Machinery	3500	.000365 (17.383)	−.0000196 (−6.90326)	.83
Transportation	3700	.000537 (13.344)	−.0000162 (−2.9603)	.47
Other metal	9999	.1446 (12.03)	−.00503 (−3.08)	.49

[1]Dependent variable: Thousand short tons of chromium per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-3.—Cobalt equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Chemical, paints, ceramics, and other.	2816, 2819, 2851, 2899, 3229, 3253, 3262	0.1482 (13.09)	−0.0066 (−4.30)	0.65
Machinery and machine tools.	3291, 3356, 3357, 3369, 3423, 3441, 3443, 3471, 3473, 3499, 3511, 3523, 3531, 3532, 3533, 3535, 3537, 3541, 3544, 3545, 3549	.0585 (12.20)	−0.0025 (−0.386)	.60
Transportation	3519, 3714, 3724	.0718 (4.68)	.0038 (1.84)	.25
Electrical	3264, 3662, 3679	.3449 (16.10)	−.0258 (−8.88)	.89

[1]Dependent variable: Thousand pounds of cobalt per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-4.—Copper equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Heavy construction	1600	0.0055 (11.24)	0.0002 (3.03)	0.48
General construction	1700	.0052 (11.46)	.00017 (2.67)	.42
Air conditioning and heating equipment.	3585	.013 (50.08)	−.00024 (−6.69)	.82
Household appliances	3630	.0095 (29.75)	−.00009 (−2.16)	.32
Motor vehicle parts and accessories.	3710	.0046 (16.35)	.00004 (.97)	.09

[1]Dependent variable: Thousand short tons of refined reported copper per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-5.—Lead equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Batteries	3691	0.523	−0.0066	0.40
		(27.68)	(−2.58)	
Gasoline additives	2869	.0081	−.00049	.95
		(30.46)	(−13.56)	
General construction	1520	.00033	−.000008	.72
		(28.17)	(−5.07)	
Heavy construction	1540	.0005	−.00001	.54
		(20.53)	(−3.4)	
Ammunition	3482	.168	−.0059	.18
		(5.76)	(−1.47)	
Pigments	2816	.0029	−.0001	.77
		(22.66)	(−5.8)	

[1]Dependent variable: Thousand short tons of primary and secondary lead per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-6.—Manganese equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Transportation	3700	0.0002	−0.00002	0.85
		(21)	(−7.5)	
Construction	1500, 1600, 3440	.00305	−.00011	.79
		(20.5)	(−6.08)	
Machinery	3500, 3610, 3620	.0028	−.00015	.92
		(24.2)	(−10.5)	

[1]Dependent variable: Thousand short tons of manganese per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-7.—Nickel equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Fabricated metal products	3400	0.9279	−0.0289	0.62
		(18.24)	(−3.859)	
Construction	1500, 1600, 1700	.382	−.028	.79
		(11.70)	(−5.85)	
Chemical and allied products.	2800	.55	−.21	.69
		(17.12)	(−4.46)	
Machinery except electrical.	3500	.305	−.013	.75
		(17.64)	(−5.24)	
Electrical and electronic equipment.	3600	.321	−.019	.77
		(13.95)	(−5.51)	
Transportation	3700	.183	−.0005	.003
		(8.26)	(−.164)	

[1]Dependent variable: Thousand short tons of nickel per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-8.—Platinum equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Industrial chemicals	2819, 2869	6.69	−0.505	0.78
		(11.13)	(−5.71)	
Petroleum refining[2]	2911	1.90	−.07	.17
		(5.45)	(−1.35)	
Electrical and electronic	3622, 3661, 3662	4.09	−.113	.45
		(14.41)	(−2.69)	
Motor vehicle parts[3] and accessories.	3714	6.47	1.18	.55
		(2.13)	(2.92)	

[1]Dependent variable: Troy ounces of platinum per million 1977 dollars.
[2]Figures shown include platinum, palladium, and iridium.
[3]Estimation period 1974–82.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-9.—Palladium equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Industrial chemicals	2819, 2869	7.05	−0.45	0.67
		(9.82)	(−4.28)	
Petroleum refining[2]	2911	1.90	−.07	.17
		(5.45)	(−1.35)	
Electrical and electronic	3613, 3622, 3661	33.64	−1.68	.39
		(7.02)	(−2.38)	
Motor vehicle parts[3] and accessories.	3714	1.22	.44	.47
		(1.16)	(2.82)	
Medical and dental equipment and supplies.	3843	134.64	22.09	.78
		(5.13)	(5.71)	
Jewelry and precious metals	3911	12.55	−.27	.05
		(4.65)	(−.67)	

[1]Dependent variable: Troy ounces of palladium per million 1977 dollars.
[2]Figures shown include platinum, palladium, and iridium.
[3]Estimation period 1974–82.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-10.—Iridium equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Industrial chemicals	2319, 2869	0.295	−0.280	0.63
		(6.06)	(−3.91)	
Electrical and electronic	3622, 3661, 3679, 3694	.133	.011	.16
		(2.37)	(1.29)	

[1]Dependent variable: Troy ounces of iridium per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-11.—Tin equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Industrial chemicals	2819	0.2006	−0.0103	0.88
		(23.63)	(−8.225)	
Metal cans	3411	3.183	−.1313	.79
		(21.10)	(−5.90)	
Motor vehicles	3711	.147	−.0031	.29
		(13.49)	(−1.90)	
Electronics	3621, 3622, 3651, 3674, 3679	.4508	−.0220	.91
		(29.28)	(−9.70)	
Construction machinery and equipment.	3531	.1203	−.0013	.08
		(11.49)	(−.874)	
Valves, pipe fittings, metal foil and leaf, collapsible tubes.	3494, 3497, 3499	.2059	−.0040	.23
		(12.67)	(−1.66)	

[1]Dependent variable: Metric tons of tin per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-12.—Titanium sponge metal equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Aircraft engines, engine parts, auxiliary equipment.	3724, 3728	0.967	0.0082	0.01
		(5.67)	(.328)	
Fabricated plate work and special industrial machinery.	3443, 3559	.205	.0479	.64
		(2.504)	(3.97)	

[1]Dependent variable: Short tons of titanium metal sponge per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-13.—Tungsten equations[1]
(Estimation period, 1972–82)

Industry	SIC	Intercept	Slope	R-square
Machine tool accessories, metal cutting accessories, metal working machinery.	3541, 3545, 3549	0.3538 (15.806)	0.0106 (3.198)	0.53
Construction machinery	3531	.0914 (9.34)	.545 (3.78)	.61
Mining machinery	3532	.5270 (5.45)	.0342 (2.40)	.39
Oil field machinery	3533	−.0177 (13.38)	.5730 (−2.80)	.47
Electrical equipment and supplies.	3699	3.67 (7.02)	−.075 (−.973)	.10

[1]Dependent variable: Thousand pounds of tungsten per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

Table A-14.—Slab zinc equations[1]
(Estimation period, 1972–83)

Industry	SIC	Intercept	Slope	R-square
Construction:				
General	1500	0.0012 (13.98)	0.000022 (1.66)	0.24
Highway	1610	.00063 (18.03)	.000006 (1.08)	.11
Heavy	1620	.00134 (20.14)	.00003 (2.853)	.48
Motor vehicles and equipment.	3710	.0037 (17.90)	−.00016 (−5.17)	.75
Air conditioning and heating.	3585	.0044 (37.53)	−.00013 (−7.28)	.85
Heating equipment and plumbing fixtures.	3430	.0122 (17.92)	−.00041 (−4.05)	.65
Cutlery, handtools, and hardware.	3420, 3429	.0195 (23.14)	−.00104 (−8.39)	.89

[1]Dependent variable: Thousand short tons of zinc per million 1977 dollars.

NOTE.—Numbers in parentheses represent respective t-statistic.

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